Chapter 2

LIFE-CYCLE INVENTORY

A life-cycle inventory (LCI) is the identification and quantification of the material and resource inputs and emission and product outputs from the unit processes in the life cycle of a product system (Figure 2-1). For the Design for the Environment (DfE) Computer Display Project (CDP), LCI inputs include materials used in the computer display product itself, ancillary materials used in processing and manufacturing of the displays, and energy and other resources consumed in the manufacturing, use, or final disposition of the displays. Outputs include primary products, co-products, air emissions, water effluents, and releases to land. Specific unit processes for CRTs and LCDs are represented by the boxes in Figures 1-6 and 1-7, and each unit process has inputs and outputs particular to that process. Figures 2-2 and 2-3 also show each unit process for both the CRT and LCD life cycles, and graphically displays how they are linked to subsequent processes. This figure will be referred to throughout this chapter in the discussion of each life-cycle stage.

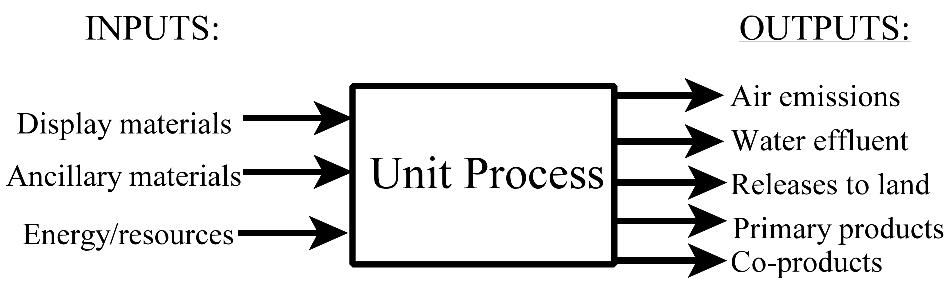

Figure 2-1. Unit process inventory conceptual diagram

This chapter describes the methods for collecting LCI data in the DfE CDP, and presents LCI results. Section 2.1 describes the general methodology for LCI data collection, while Sections 2.2 through 2.6 present the specific methodologies, data sources, data quality, limitations and uncertainties for each life-cycle stage. Section 2.7 then concludes with the combined LCI data for each monitor type.

More specifically, Section 2.2 presents the LCI methodology for the materials extraction and materials processing (i.e., "upstream") life-cycle stages, including electricity generation. Electricity is used in several processes throughout each monitor's life-cycle, and the electricity generating process is linked to the processes that use electricity. As a consequence, the inventory results from electricity generation are reported as part of the associated life-cycle stage for the process to which it is linked. For example, electricity used in manufacturing a product component is included in the manufacturing stage inventory, while electricity used during the use stage is included in the use stage inventory.

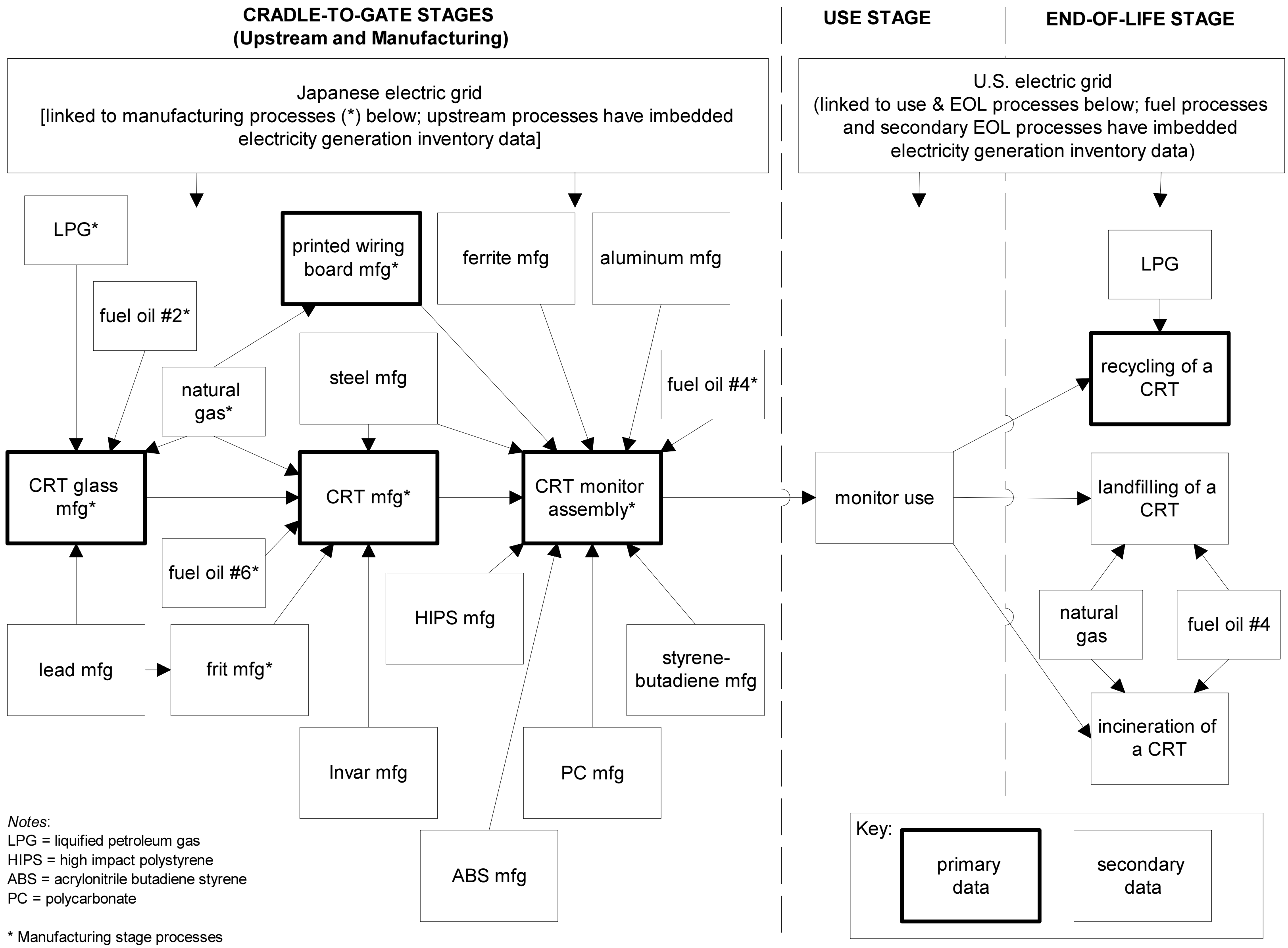

Figure 2-2. CRT linked processes

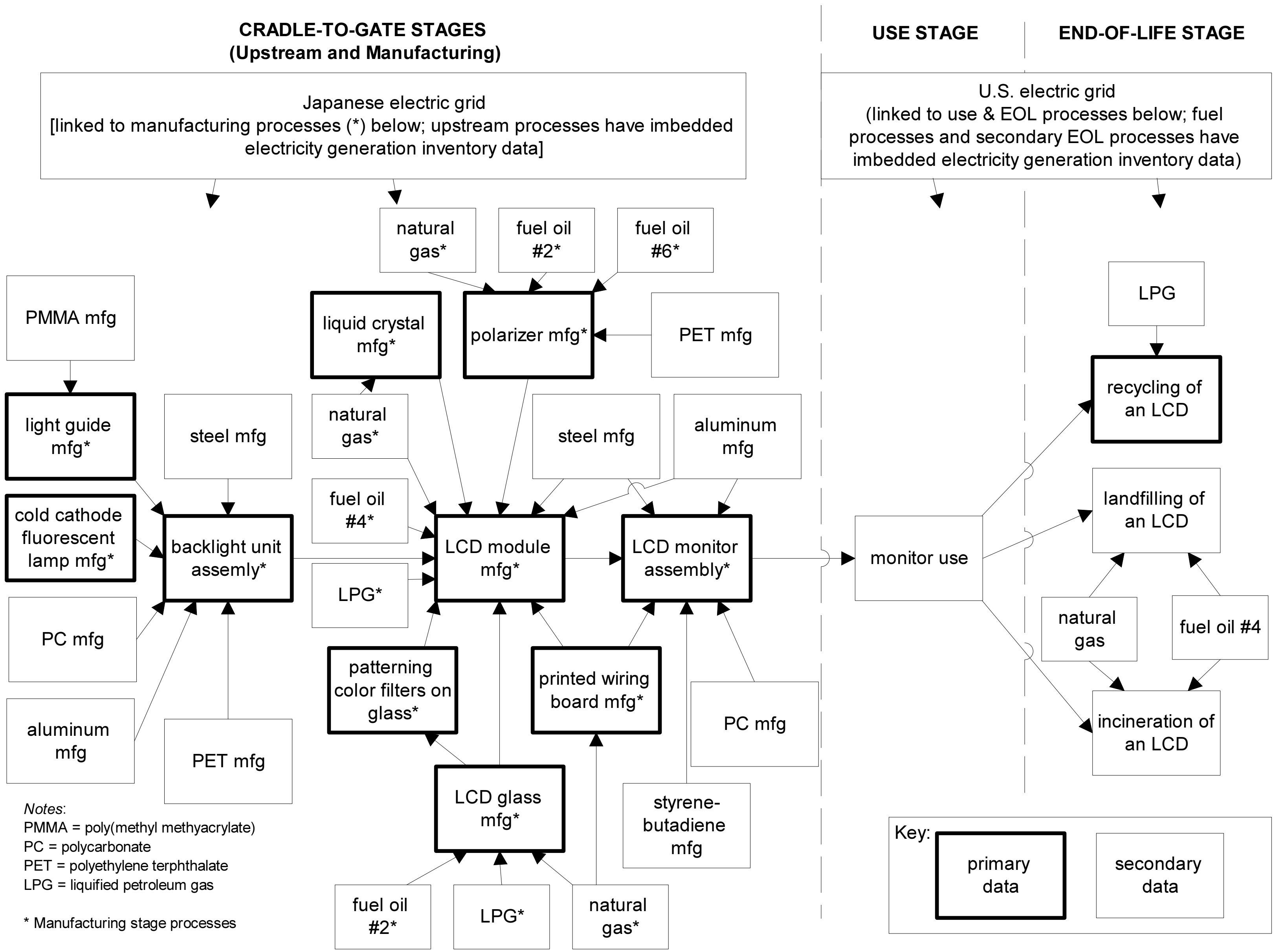

Figure 2-3. LCD linked processes

Section 2.3 presents the LCI methods for the product manufacturing life-cycle inventory, which was developed from primary data collected through questionnaires designed and sent to manufacturers for this study. Sections 2.4 and 2.5 present the methods for developing the use and end-of-life (EOL) life-cycle stage inventories, respectively. Transportation is another important aspect of a product life-cycle that can cause environmental impacts. Information related to the transport of materials, products, and wastes is presented in Section 2.6. As the final section of Chapter 2, Section 2.7, summarizes and discusses the entire inventory data over the life-cycles of the CRT and LCD computer monitors. Sensitivity analyses are also discussed in Section 2.7.

2.1 GENERAL METHODOLOGY

This section describes the data categories evaluated in the CDP LCI, the decision rules used to determine which materials extraction and materials processing life-cycle stages (e.g., "upstream" processes) to evaluate in the study, and data collection methods. It also describes procedures for allocating inputs and outputs from a process to the product of interest (e.g., a display or display component) when the process is used in the manufacture, recycle, or disposal of more than one product type at the same facility. Finally, it describes the data management and analysis software used for the project and methods for maintaining overall data quality and critical review.

2.1.1 Data Categories

Table 2-1 describes the data categories for which inventory data were collected, including material inputs, energy inputs, natural resource inputs, emission outputs, and product outputs. Inventory data were normalized to mass per functional unit (in the case of material and resource inputs and emission or material outputs), megajoules (MJ) per functional unit (in the case of energy inputs), or the number of components per functional unit (in the case of display components). As discussed in Section 1.3, the functional unit is one desktop computer display over its lifespan.

Data that reflected production for one year of continuous processes were scaled to one functional unit. Thus, excessive material or energy associated with startups, shutdowns, and changeovers were assumed to be distributed over time. Consequently, any environmental and exposure modeling associated with the impact assessment reflects continuous emissions such that equilibrium concentrations may be assumed. If the reporting year was less than one year for any inventory item, the analysis was adjusted as appropriate.

Table 2-1. LCI data categories

Data Category	Description
Material inputs (kg per functional unit)	
Primary materials	Actual materials that make up the final product for a particular process. These can be individual materials or a combination of materials that comprise a component part.
Ancillary (process) materials	Materials that are used in the processing of a product for a particular process. Process materials from monitor manufacturing could include, for example, etchants used during photolithography which are washed away and not part of the final product, but are necessary to manufacture the product.
Energy inputs (MJ per functional unit)	
Process energy	Energy consumed by any process in the life-cycle.
Precombustion energy	The energy expended to extract, process, refine, and deliver a usable fuel for combustion.
Transportation energy	Energy consumed in the transportation of the materials or products in the life cycle.
Natural resource inputs (kg per functional unit)	
Non-renewable resources	Materials extracted from the ground that are non-renewable, or stock, resources (e.g., coal).
Renewable resources (e.g., water)	Water or other renewable, or flow, resources (e.g., limestone) are included in the analysis. Renewable resource data values are presented in mass of water consumed for a particular process.
Emissions outputs (kg per functional unit)	
Air	Mass of a product or material that is considered a pollutant within each life-cycle stage. Air outputs represent actual gaseous or particulate releases to the environment from a point or diffuse source, after passing through emission control devices, if applicable.
Water	Mass of a product or material that is considered a pollutant within each life-cycle stage. Water outputs represent actual discharges to either surface or groundwater from point or diffuse sources, after passing through any water treatment devices.
Solid wastes	Mass of a product or material that is deposited in a landfill or deep well. Represents actual disposal of either solids or liquids that are deposited either before or after treatment (e.g., incineration, composting), recovery, or recycling processes.
Products (kg of material or number of components per functional unit)	
Primary products	Material or component outputs from a process that are received as input by a subsequent unit process within the display life cycle.
Co-products	Material outputs from a process that can be used, either with or without further processing, that are not used as part of the final functional unit product.

Data were also collected on the final disposition of emissions outputs, such as whether outputs are recycled, treated, and/or disposed. This information helps determine what impacts will be calculated for a particular inventory item. Methods for calculating impacts are discussed in Chapter 3, Life-Cycle Impact Assessment. The dispositions used for this project are as follows:

- air,
- surface water,
- landfill,
- land (other than landfill),
- treatment,
- recycling/reuse, and
- deep well injection.

Given the enormous amount of data involved in inventorying all of the inputs and outputs for a product system, life-cycle assessment (LCA) practitioners typically employ decision rules to make the data collection manageable and representative of the product system and its impacts. Section 2.1.2 discusses the decision rules used in the CDP LCI.

2.1.2 Decision Rules

In an LCA, the materials extraction and materials processing life-cycle stages (referred to as "upstream" life-cycle stages) include processes for extracting raw materials from the earth and processing those raw materials into the materials used in the manufacture of the product of interest. Examples of upstream processes include the mining of iron ore and its processing with other materials into steel sheet or the extraction of petroleum from underground reserves and its conversion into plastic pellets. A continuing challenge for LCA practitioners is to collect all the appropriate data for a product system, including data for these upstream processes as well as data for product manufacturing, use, and disposal processes. In this project, decision rules as to what inventories should be included as upstream processes in the overall modeled life-cycle are based on the materials used to manufacture the computer monitors. Also, which component parts to include in the model depends on these decision rules. In considering upstream materials, a combination of several factors, including availability of existing data were considered. For considering which component manufacturing processes to include, the decision rules, plus manufacturers willingness to participate, factored into our overall scope of what was included in the analysis.

To help determine which upstream processes to include in the CDP LCI, first the bill of materials (BOM) of the component parts and the materials that make up those parts (Tables 1-3 and 1-4) was reviewed. The quantities of those materials identified by MCC can be found in Industry Profile Document (MCC, 1998). Using the MCC BOM allowed work to begin on selecting and collecting upstream data before the actual BOM from the manufacturing stage was obtained from the project's primary data collection effort. Final decisions on which upstream processes to include were based on the BOM developed from data collected from manufacturers. Tables 2-2 and 2-3 list the BOMs of the primary material inputs from the manufacturing of the CRT and LCD, respectively. The mass quantities given in the tables are the primary material inputs to the manufacturing process and would be equivalent to the amount of material in the final product plus excess or waste materials. While this is not exactly equivalent to the mass of each material that makes up a finished product, it does represent the mass of primary materials used to manufacture the finished product at participating facilities. Details of how these data were obtained are presented in Section 2.3, which describes the manufacturing stage inventory.

Table 2-2. Bill of primary material inputs for a 17" CRT monitor

Material/Component		Mass (kg) [a]		weight % of total inputs [a]	
	Sub-component				
Lead oxide glass		9.76		46.1%	
	Lead		0.45		2.1%
Steel		5.16		24.4%	
Plastics		3.04		14.4%	
	Polycarbonate (PC)		0.92		4.36%
	Styrene-butadiene co-polymer		0.83		3.91%
	Polyethylene ether (PEE)		0.74		3.47%
	Acrylonitrile-butadiene-styrene (ABS)		0.32		1.52%
	High-impact polystyrene (HIPS)		0.15		0.71%
	Triphenyl phosphate		0.05		0.25%
	Tricresyl phosphate		0.02		0.11%
	Phosphate ester		0.01		0.04%
Printed wiring boards (PWB) and components		0.85		4.00%	
Cables/wires		0.45		2.13%	
Aluminum (heat sink)		0.27		1.29%	
Nickel alloy (invar)		0.27		1.29%	
CRT shield assembly		0.24		1.14%	
Ferrite		0.17		0.80%	
Deflection yoke assembly		0.15		0.71%	
Demagnetic coil		0.13		0.60%	
Video cable assembly		0.11		0.54%	
Power cord assembly		0.11		0.54%	
Electron gun		0.10		0.47%	
CRT magnet assembly		0.08		0.36%	
Audio cable assembly		0.07		0.34%	
Frit		0.07		0.32%	
Solder		0.03		0.13%	
Phosphors		0.02		0.08%	
Aquadag		0.02		0.07%	
Other (misc.)		0.06		0.30%	
TOTAL		**21.16**		**100%**	

[a] Based on the primary material inputs to the manufacturing process, including material in the final product plus excess or waste materials.

Table 2-3. Bill of primary material inputs for a 15" LCD monitor

Material/Component	Subcomponent	Mass (kg) [a]		weight % of total inputs [a]	
Steel		2.53		44.12%	
Plastics		1.78		30.98%	
	Polycarbonate (PC)		0.52		9.00%
	Poly(methyl methacrylate) (PMMA)		0.45		7.80%
	Styrene-butadiene copolymer		0.36		6.31%
	Polyethylene ether (PEE)		0.30		5.23%
	Triphenyl phosphate		0.09		1.61%
	Polyethylene terephthalate (PET)		0.06		1.03%
Glass		0.59		10.31%	
Printed wiring boards (PWB) and components		0.37		6.52%	
Cables/wires		0.23		4.08%	
Aluminum (heat sink, transistor)		0.13		2.34%	
Solder (60% tin, 40% lead)		0.04		0.66%	
Color filter pigment		0.04		0.65%	
Polyvinyl alcohol (PVA) (for polarizer)		0.01		0.15%	
Liquid crystals, for 15" LCD, unspecified [b]		0.0023		0.04%	
Backlight lamp (cold cathode fluorescent lamp, CCFL)		0.0019		0.03%	
	Mercury		3.99E-06		0.0001%
Transistor metals, other (e.g., Mo, Ti, MoW)		0.0019		0.03%	
Indium tin oxide (ITO) (electrode)		0.0005		0.01%	
Polyimide alignment layer		0.0005		0.01%	
Other (e.g., adhesives, spacers, misc.)		0.0031		0.05%	
TOTAL		5.73		100%	

[a] Based on the primary material inputs to the manufacturing process, including material in the final product plus excess or waste materials.
[b] This does not include all liquid crystals, as those specified as individual chemicals are in very small amounts and included in the "other" category.

The decision rule process begins by assessing the materials and components in Tables 2-2 and 2-3 for the following attributes:

1. *The mass (M) contribution of each component and material in the display.* The mass is important in order to account for the majority of materials and components that make up a display, but also because the more significant the material or component by mass, the more materials and resources may be required to manufacture the material or component and thus it may have a significant environmental impact.

2. *Materials that are of known or suspected environmental (Env) significance (e.g., toxic).* As this is an environmental life-cycle assessment, consideration of materials or components that are known to or are suspected to exhibit an environmental hazard are also included to the extent feasible.

3. *Materials that are known or suspected to have a large energy (E) contribution to the systems energy requirements.* Energy impacts are of great interest to the use and manufacture of display monitors and, therefore, priorities were given to including materials or components that are known to or suspected to consume large amounts of energy.

4. *Materials or components that are functionally (F) significant to the display.* "Functionally significant" is defined as important to the technically successful operation of the display. For example, the liquid crystals in an AMLCD would be "functionally significant" while screws, gaskets, or the plastic cover would not be.

5. *Materials or components that are physically (P) unique in the CRT as compared to the LCD and vice versa.* The physical uniqueness of a material or component could be identified by chemical makeup or by size. An example of the latter would be if the plastic casing for the CRT and LCDs were made of the same material, but the CRT casing had substantially more material by weight.

The priority scheme depicted in Figure 2-4 provides guidelines for applying the CDP decision rules. Material or component inputs that account for more than five percent of the total mass of a display technology were given top priority for data collection, as were those of known or suspected environmental or energy significance and those that are functionally significant or physically unique. Of less emphasis in trying to obtain data, but still included if possible, were materials or components that are functionally significant but physically similar to those in the other technologies, and those that were between 1 and 5% of the total mass of the display. Recognizing the limitations of project resources, materials or components that account for less than one percent of total mass or are not otherwise significant or unique were excluded *a priori*.

Based on this hierarchy and on review of the preliminary BOMs, Tables 2-4 and 2-5 present how components were rated based on the priority scheme, and which ones were included in the analysis. If a material or component was included in the analysis as a separate process, it is listed in the last column of Tables 2-4 and 2-5 by what life-cycle stage that process is in (i.e., upstream or manufacturing process). If a material or component was only included as part of another process, and not as a separate process in the profile, the process in which that material or component is found is provided in the last column.

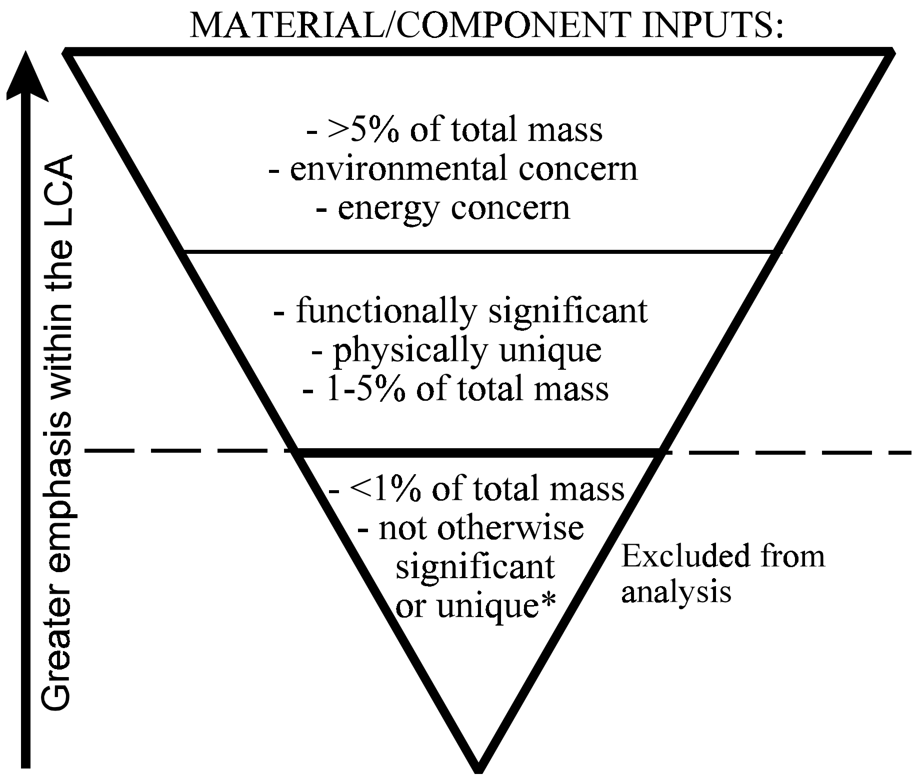

Figure 2-4. Decision rule guidelines

*e.g., materials are excluded if they are not of known environmental significance (for example, toxic) or are not physically unique.

Table 2-4. Decision rule priorities and scope of analysis for the primary material inputs of the 17" CRT monitor

Material/Component	Sub-component	Decision rule	Included in analysis as:
Lead oxide glass		M, F, P, E, Env	manufacturing process
	Lead	P, Env	upstream process
Steel		M	upstream process
Plastics		---	-----
	Polycarbonate (PC)	M	upstream process
	Styrene-butadiene co-polymer	M	upstream process
	Polyethylene ether (PEE)	M	part of monitor assy. process
	Acrylonitrile-butadiene-styrene (ABS)	M	upstream process
	High-impact polystyrene (HIPS)	none	upstream process
	Triphenyl phosphate	none	part of monitor assy. process
	Tricresyl phosphate	P	part of monitor assy. process
	Phosphate ester	P	part of monitor assy. process
Printed wiring boards (PWB) and components		M, E, Env	manufacturing process
Cables/wires		none	part of monitor assy. process
Aluminum (heat sink)		M (<5%), E	upstream process
Nickel alloy (invar)		M (<5%), P	upstream process
CRT shield assembly		none	part of monitor assy. process
Ferrite		P	upstream process
Deflection yoke assembly		F, P	part of monitor assy. process
Demagnetic coil		F, P	part of monitor assy. process
Video cable assembly		none	part of monitor assy. process
Power cord assembly		none	part of monitor assy. process
Electron gun		F, P	part of tube mfg. process
CRT magnet assembly		P	part of monitor assy. process
Audio cable assembly		none	part of monitor assy. process
Frit		F, P, E, Env	manufacturing process
Solder		Env	part of monitor assy. process
Phosphors		F, P	part of tube mfg. process
Aquadag		F, P	part of tube mfg. process
Other (misc.)			miscellaneous

M = mass is greater than 1% of the total display weight; **Env** = environmental/toxic concern; **E** = energy concern;
F = functional (technological) importance; **P** = physically unique.
Note: The CRT processes included in the CDP LCA were presented in Figures 1-6 and 2-2.

Table 2-5. Decision rule priorities and scope of analysis for the primary material inputs of the 15" LCD monitor

Material/Component	Sub-component	Decision rule	Included in analysis as:
Steel		M	upstream process
Plastics		---	-----
	Polycarbonate (PC)	M	upstream process
	Poly(methyl methacrylate) (PMMA)	M, P	upstream process
	Styrene-butadiene co-polymer	M	upstream process
	Polyethylene ether (PEE)	M	part of monitor assy. process
	Triphenyl phosphate	M (<5%)	part of monitor assy. process
	Polyethylene terephthalate (PET)	M (<5%), P	upstream process
Glass		M	manufacturing process
Printed wiring boards (PWB) and components		M, E, Env	manufacturing process
Cables/wires			part of monitor assy. process
Aluminum (heat sink, transistor)		M (<5%), E	upstream process
Solder (60% tin, 40% lead)		Env	part of monitor assy. & module mfg. processes
Color filter pigment		P	part of color filter patterning
Polyvinyl alcohol (PVA) (for polarizer)		none	part of polarizer mfg. process
Liquid crystals, for 15" LCD		F, P, Env	manufacturing process
Backlight lamp (cold cathode fluorescent lamp)		F, P, Env	manufacturing process
	Mercury	Env	part of backlight lamp process
Transistor metals, other (e.g., Mo, Ti, MoW)		F, P	part of module mfg. process
Indium tin oxide (ITO) (electrode)		F, P	part of module mfg. process
Polyimide alignment layer		F, P	part of module mfg. process
Other (e.g., adhesives, spacers, misc.)			miscellaneous

M = mass is greater than 1% of the total display weight; **Env** = environmental/toxic concern; **E** = energy concern;
F = functional (technological) importance; **P** = physically unique.
Note: The LCD processes included in the CDP LCA were presented in Figures 1-7 and 2-3.

2.1.3 Data Collection and Data Sources

Data were collected from both primary and secondary sources. Primary data are directly accessible, plant-specific, measured, modeled, or estimated data generated for the particular project at hand. Secondary data are from literature sources or other LCAs, but are specific to either a product, material, or process used in the manufacture of the product of interest.

Table 2-6 lists the types of data (primary or secondary) used for each life-cycle stage in the CDP LCI. In general, greater emphasis was placed on collecting data and/or developing models for product manufacturing, use, and end-of-life. Primary data were collected from product and component manufacturers (in the U.S., Japan, and Korea), and CRT recyclers who voluntarily agreed to participate in the project. When proprietary data were involved, the University of Tennessee (UT) Center for Clean Products and Clean Technologies entered into confidentiality agreements with the affected company. In addition, to both protect confidentiality and better represent the various manufacturing processes, data for particular processes that were collected from more than one company, where possible, and aggregated. Attempts were made to get at least two companies to contribute data for each particular process in the manufacturing life-cycle stage, which resulted in some process datasets being the aggregate of multiple (2-7) companies data. However, this was not feasible in every case and some datasets were simply the data of one company. Details of the data aggregation methods are provided in Section 2.3.

Data for the use stage were modeled specifically for this project by UT researchers, but were based on secondary data (i.e., secondary data were built upon to create the data used in the inventory for the use life-cycle stage). Data associated with the electricity generation were also based on secondary data, but modeled for this project. Transportation information (e.g., transportation mode and distances) were collected from the manufacturers that provided primary data. These data were linked to secondary data inventories of fuel inputs and emissions outputs for various types of transport vessels. Transportation data cover movement of materials and components both into and out of a facility, but do not include transportation of packaging or distribution of the finished display to the consumer. Finally, secondary data were used for upstream processes. More details on each of these data collection efforts are provided in subsequent sections of this chapter.

Table 2-6. Data types by life-cycle stage

Life-cycle stage	Data types
Upstream (materials extraction and processing)	Secondary data.
Product and component manufacturing	Primary data, except secondary data used for frit.
Use	Modeled using secondary data; maintenance and repair are not included in the analysis.
Final disposition (recycling and/or disposal)	Modeled using secondary data plus primary data from CRT recycling facilities.
Packaging, transportation, distribution	Primary data from product and component manufacturers for transport mode and distance; secondary data for fuel inputs and emissions outputs for the transport vessel. Packaging and distribution not included.

In some instances, neither primary nor secondary data were available. For example, CRTs are a much more mature technology than the LCD, and end-of-life (EOL) data are much less prevalent for the LCD than for the CRT. Where primary and secondary data are lacking, various assumptions and modeling serve as defaults.

2.1.4 Allocation Procedures

An allocation procedure is required when a process within a system shares a common management structure, or where multiple products or co-products are produced. In the CDP LCI allocation procedures are used when processes or services associated with the functional unit (e.g., a desktop computer display over its lifetime) are used in more than one product line at the same facility (e.g., notebook computers, televisions). For example, transistors are used in LCD desktop computer displays, but also in other LCD technologies, such as notebook computer displays. If a facility uses a single process to manufacture transistors for both desktop and notebook computer display, inputs and outputs are allocated among the product lines to avoid over-estimating the environmental burdens associated with the product under evaluation.

The International Standards Organization (ISO, 1996) recommends that wherever possible, allocation should be avoided or minimized. This may be achieved by sub-dividing the unit process into two or more sub-processes, some of which can be excluded from the system under study. In the example above, if a manufacturer of transistors supplied only desktop computer LCD manufacturers, no allocation would be necessary from that manufacturer. However, it is more likely that the transistor manufacturer would have a larger customer base, including manufacturers of various products other than liquid crystal desktop computer displays. This requires allocation of flows from the manufacturing of transistors for several products to those associated only with desktop computer displays. As suggested by ISO, if sub-processes within the transistor facility can be identified that distinguish between transistors manufactured for LCDs and for other products, the latter sub-processes can be eliminated from the analysis, thus reducing allocation procedures.

In this study allocation procedures are used as follows:

- *Inventory data for utilities and services common to several processes are allocated to reflect the relative use of the service.* For example, fuel inputs and emission outputs from electric utility generation are allocated to a display or display component according to the actual or estimated electricity consumed during the manufacture, use, or final disposition of the product. Similarly, fuel inputs and emission outputs from commercial transport of a display component to a display assembler are allocated to the display component according to the mass of the component, the distance traveled, and the fraction of the transport vehicle's capacity occupied by the number of components shipped.
- *Where a unit process produces co-products, the burdens associated with the unit process are allocated to the co-product on a mass basis.* In the transistor example above, burdens are allocated according to the total mass of transistors used in desktop displays and the mass used in notebook computers. Total mass can be calculated from sales records which document the number of transistors delivered to different customers and measured mass of a set number of transistors.

Allocation is also necessary when a single process produces both energy and products. In this case, the inputs are partitioned among the energy and products, as appropriate, to avoid allocating inapplicable chemical burdens to energy production. However, this scenario was not encountered in the CDP LCI.

2.1.5 Data Management and Analysis Software

The data that were collected for this study were either obtained from questionnaires developed for this project, from existing databases, or from primary or secondary data collected by the UT Center for Clean Products and Clean Technologies. All these data were transferred to spreadsheets, which were then imported into a Life-Cycle Design Software Tool developed by the Center for Clean Products and Clean Technologies with funding from the EPA Office of

Research and Development and Saturn Corporation. The software tool was developed to store and organize life-cycle inventory data and to calculate life-cycle impacts for a product profile. Written using Microsoft FoxPro programming software, the tool is designed to allow flexibility in conducting life-cycle design and life-cycle assessment functions. It provides the means to organize inventory data, investigate alternative scenarios, evaluate impacts, and assess data quality.

The UT Life-Cycle Design Software Tool organizes data in such a way that each process inventory is independent. Customized "profiles" (e.g., the manufacture of a CRT or the whole life-cycle of an LCD) can be developed by linking processes together. The tool has the flexibility to modify or replace any particular process within a profile to evaluate potential alternatives. The data provided in this study may serve as a baseline to compare alternatives or modifications to particular processes. The models developed for the life-cycles of the CRT and LCD in this study can remain useful as many of the individual processes in the CRT and LCD life-cycles will likely remain constant (e.g., steel manufacturing, plastics manufacturing). Changes to specific processes can be made to conduct analyses of current or emerging process or technology changes. Relatively quick life-cycle analyses can be conducted on future product or process improvements, given the baseline data already available through this study.

2.1.6 Data Quality

LCI data quality can be evaluated based on the following data quality indicators (DQIs): (1) the source type (i.e., primary or secondary data sources); (2) the method in which the data were obtained (i.e., measured, calculated, estimated); and (3) the time period for which the data are representative. LCI DQIs are discussed further in *Life-Cycle Assessment Data Quality: A Conceptual Framework* (SETAC, 1994). CDP data quality for each life-cycle stage is discussed in detail in Sections 2.3 through 2.6 and summarized below.

For the primary data collected in this project, participating companies reported the method in which the data were obtained and the time period for which the data are representative. Data from the 1997-2000 time period were sought, with the most recent data preferred. Similarly, the time period of secondary data and method in which the data were originally obtained was also recorded, where available. Secondary data cover a broader time period, with data for most materials from the 1997 to 1998 time period, and data for most fuels from the 1983 to 1993 time period.

Anomalies and missing data are common hurdles in any data collecting exercise. Anomalies are extreme values within a given data set. Any anomaly identified during the course of this project that is germane to project results was highlighted for the project team and investigated to determine its source (e.g., mis-reported values). If the anomaly could be traced to an event inherently related to the process, it was left in the data set. If, however, the anomaly could not be accounted for, it was removed from the data set. Specific anomalies highlighted by the project team are discussed in Section 2.7, Summary of Life-Cycle Inventory Results.

We attempted to account for missing data by replacing it hierarchically. That is, if specific primary data were missing, secondary data were used. Where neither primary nor secondary data were available, such as data on the percent of LCD desktop displays recycled or remanufactured, assumptions were made and a sensitivity analysis was performed. In the cases where no data were found or reasonable assumptions could not be made, these deficiencies are reported.

Any proprietary information required for the assessment was subject to confidentiality agreements between the Center for Clean Products and Clean Technologies and the participating company. Proprietary data are presented as aggregated data to avoid revealing the source. Further, any averaged process data obtained from fewer than three companies are also aggregated to avoid revealing individual inventory items from individual companies.

2.1.7 Critical Review

Critical review is a technique to verify whether an LCA has met the requirements of the study for methodology, data, and reporting, as defined in the goal definition and scoping phase. A critical review process was maintained in the CDP LCA to help ensure that the following criteria were met:

- the methods used to carry out assessments are consistent with the EPA, SETAC, and ISO assessment guidelines;
- the methods used to carry out assessments are scientifically and technically valid within the LCA framework;
- the data used are appropriate and reasonable in relation to the goals of the study;
- the interpretations reflect the limitations identified and the goals of the study; and
- the study results are transparent and consistent.

A project Core Group and Technical Work Group, both consisting of representatives from industry, academia, and government, and EPA's DfE Work Group provided critical reviews of the assessment. Members of these groups are listed in Appendix C, Critical Review. The Core Group served as the project steering committee and was responsible for approving all major scoping assumptions and decisions. The Technical Work Group and the DfE Work Group provided technical guidance and reviews of all major project deliverables including the final LCA report.

In addition to the critical review process, primary data collected were double-checked with the original source to ensure that their data are presented accurately. Additional details on the data verification process for primary data are presented in Sections 2.3 and 2.5.

2.2 MATERIALS EXTRACTION AND MATERIALS PROCESSING (UPSTREAM LIFE-CYCLE STAGES)

2.2.1 Methodology

The inventories included in the materials extraction and materials processing (upstream) life-cycle stages are those of the major primary materials found in the CRT or LCD monitor, as well as major ancillary materials required to manufacture the monitors. Inventories for electricity generation and fuels, which may be used in several life-cycle stages (e.g., to manufacture the products or to use the products), are also presented.

The inventories for extraction and processing of major materials were obtained from existing LCI databases. Electricity generation inventories were developed for this project from secondary sources that describe the distribution of fuels for different electric grids and the fuel inputs and emission outputs associated with different fuel types. The methodologies for developing these inventories are summarized below.

2.2.1.1 Upstream materials processes

Materials for which upstream processes were included in the CRT and LCD life-cycles were selected based on the decision rules described in Section 2.1.2, as well as the availability of secondary data for those materials. An attempt was made to include materials with a mass greater than or equal to one percent of the overall inputs to the product manufacture, or materials that may contribute to a large amount of energy use or have environmental concern. Tables 2-4 and 2-5 in Section 2.1.2 listed the decision criteria for primary materials/components that are included either as separate processes or as part of another process. The upstream materials processes for which inventory data were obtained for this project are presented in Table 2-7.

To determine which source or sources of secondary data to use, nine LCI databases were evaluated against 11 selection criteria in a technical memorandum presented to the project review teams (see Appendix D). Based on this analysis the project team chose the Environmental Information and Management Explorer (EIME) database and the Database for Environmental Analysis and Management (DEAM), two life-cycle inventory databases developed by the *Ecobilan* (Ecobalance) Group (*Ecobilan,* 1999). EIME was developed by *Ecobilan* specifically for electronics and the electronics industry and covers many of the materials specific to the CDP, while the DEAM database includes materials not covered by EIME. Combined, these databases contain detailed inventories of materials extraction and processing activities for most of the materials of interest in this project.

In the *Ecobilan* inventory for a particular material, the functional unit is a set mass of the material. Inputs and outputs are therefore given in terms of mass or other appropriate unit per unit mass of material. These data were imported into the UT Life-Cycle Design Software Tool discussed in Section 2.1.5, where they were linked to the mass of material used in the manufacture of a display monitor to develop inventories specific to the CDP. The associated amounts of each material were presented in Tables 2-2 and 2-3 in Section 2.1.2. How these materials are linked to other processes in the CRT and LCD profiles are shown in Figures 2-2 and 2-3 at the beginning of this chapter.

The materials inventories from *Ecobilan* also contain data for electricity generation, as appropriate, and in some cases, for transportation. Electricity generation and transportation data that were included in the *Ecobilan* inventories could not be separated from the inventory data for materials extraction and conversion processes. Therefore, when electricity generation and transport data were included in the *Ecobilan* inventories, the electricity and transport data collected specifically for this project were not used with the upstream process data.

Table 2-7. Materials having upstream processes included in the CDP LCA

Material	CRT	LCD
METALS		
aluminum	✓	✓
ferrite	✓	
lead	✓	
nickel alloy (invar)	✓	
steel	✓	✓
POLYMERS		
acrylonitrile-butadiene styrene (ABS)	✓	
high impact polystyrene (HIPS)	✓	
polycarbonate (PC)	✓	✓
polyethylene terphthalate (PET)		✓
poly(methyl methacrylate) (PMMA)		✓
styrene-butadiene co-polymer	✓	✓
ANCILLARY MATERIALS		
natural gas (used to represent LNG)		✓

2.2.1.2 Electric grids

Electricity is used in several processes throughout the life-cycle of the CRT and LCD monitors, and in some instances in large amounts. Therefore, the inventory for electricity generation is included in the scope of this project.

As described in Chapter 1, Section 1.4.2, the geographic boundaries of this project are worldwide for upstream and product manufacturing processes and limited to the United States for the use and end-of-life stages. In addition, most CRT and LCD manufacturing is done in Asia and most product manufacturing data collected in this study were from the United States or Japan, except for two LCD manufacturing data sets collected from Korean manufacturers. Therefore, the inventory associated with electricity generation during manufacturing was based on either the Japanese or U.S. electric grids, depending on the particular process or component being manufactured. Where data were obtained from more than one country for the same process, only one electric grid inventory could be used for a single process. In these cases, the Japanese electric grid was used since the majority of manufacturing data are from Japanese companies. The inventory for electricity generated during use and EOL processing was based on the U.S. electric grid.

The methodology and results for the electricity generation inventories are detailed in Appendix E, which presents the electric grid technical memorandum prepared for this project. The inventories were developed by first compiling U.S. inventory data for each of the major generation categories or fuel types, including electricity generated from coal, gas, petroleum, and nuclear fuels. These inventories were then combined with data on net electricity generation by fuel type in the U.S. and Japanese electric grids (Table 2-8) to develop the country-wide electric generation inventories. The inputs and outputs for the electricity generation inventories are presented in terms of mass or radioactivity per kWh of electricity generated. Inventories were not included for hydroelectric and renewable energy generation categories due to the scarcity of data on inputs and outputs for these categories. In addition, renewables account for only a small fraction of total U.S. electricity generation.

Table 2-8. Net electricity generation by fuel type

Fuel	Net electricity generation	
	United States (percent)	Japan (percent)
Coal	57	18
Gas	9	20
Petroleum	3	21
Nuclear	20	31
Hydro	11	9
Other	<1	1

Sources: U.S.: EIA, 1999a; Japan: EIA, 1997; FEPC, 1996.

Note that the Japanese grid inventory is based on the same fuel-specific inventories developed for the U.S. grid, but uses the average distribution of fuels for the Japanese grid (EIA, 1997, FEPC, 1996). This introduces some uncertainty into the Japanese electric grid since Japanese technologies, efficiencies, and pollution control techniques are likely to differ somewhat from their U.S. counterparts. However, the U.S. fuel-specific inventories were used to conserve project resources, rather than expending considerable effort on collecting inventory data from Japanese utilities.

The electricity generation inventories presented in Appendix E are shown as separate process inventories. However, in the overall analysis, they are linked to the manufacturing, use and EOL life-cycle stages, as appropriate. That is, where electricity is used in a process in any of those life-cycle stages, the inputs and outputs from generating the amount of electricity needed is allocated to that process. Note that the U.S. and Japanese electricity generation inventories developed for this project are not linked to the upstream life-cycle stages for materials used to manufacture CRT and LCD desktop computer displays. Electricity generation data were already included in the upstream material inventories received from *Ecobilan*.

2.2.1.3 Fuels

Several fuels are used in manufacturing and end-of-life processes during the life-cycle of the CRT and LCD monitors, and in some instances in large amounts.[1] Therefore, fuel production inventories are included in the scope of this project. These inventories are included in the life-cycle stage in which the fuels are actually consumed (e.g., product manufacturing or end-of-life) instead of in the upstream (materials processing) life-cycle stage. The following fuel inventories are included in both the CRT and LCD LCIs:

- natural gas (also used to represent LNG),
- liquified petroleum gas (LPG),
- fuel oil #2 (distillate),
- fuel oil #6 (residual), and
- fuel oil #4 (average of residual and distillate).

Fuel inventories were obtained from *Ecobilan*. In the *Ecobilan* inventories, the functional unit is a set mass of the material, with inputs and outputs given in terms of mass or other appropriate unit per mass of material (product) produced. These data were imported into the UT Life-Cycle Design software tool where they were linked to the mass of fuel used in different processes in the life-cycle of a display. How the fuel processes are linked to other processes in the CRT and LCD profiles was shown in Figures 2-2 and 2-3.

2.2.2 Data Sources and Data Quality

2.2.2.1 Upstream material and fuel processes

Table 2-9 summarizes data source and data quality information for the data received from *Ecobilan*, which are all secondary data for the purposes of the CDP. In addition to information about CDP data quality indicators (e.g., original source of data, year of data, method in which data were obtained, and geographic boundaries), the table lists whether or not electricity generation or transport data were included in the inventories. This information is important because: (1) electricity generation and transportation data are not from the same sources and therefore are not necessarily consistent among data sets; and (2) transportation data are not included in several of the upstream processes, and are thus a data gap for those processes.

As revealed in Table 2-9, the *Ecobilan* data were derived from various sources, including European data sources and U.S. data sources. In addition, the temporal boundaries of the data vary, with some data being as recent as 1998 but others being from as early as 1975. Electricity generation data are included in all of the inventories, but transportation data are only included in six of 16 data sets. All of these factors create some inconsistencies among the data sets and reduce the data quality when used for the purposes of the CDP. However, this is a common difficulty with LCA, which often uses data from secondary sources for upstream processes to avoid the tremendous amount of time and resources required to collect all the needed data.

[1] Fuels are also used in the materials processing life-cycle stage, but fuel production processes should already be accounted for in the materials inventories obtained from *Ecobilan*.

Table 2-9. Data sources and data quality for the *Ecobilan* inventories [a]

Material	Electricity generation included?	Transport included?	Year of data	Original source [b]
METALS				
aluminum	Y	--	--	ETH
ferrite	Y	--	--	not provided
lead	Y	--	Unknown	ETH
nickel-alloy (invar) [c]	Y	Y (nickel)	1991 (nickel)	ETH
steel	Y	--	1975-1990 [d]	FOEFL, others [d]
POLYMERS				
acrylonitrile-butadiene styrene (ABS)	Y	Y [e]	1997	Boustead
high impact polystyrene (HIPS)	Y	Y [e]	1997	Boustead
polycarbonate (PC)	Y	Y [e]	1997	Boustead
polyethylene terphthalate (PET)	Y	Y [e]	1998	Boustead
poly(methyl methacrylate) (PMMA)	Y	Y [e]	1997	Boustead
styrene-butadiene co-polymer [f]	Y	Y [e]	1997	Boustead
FUELS				
natural gas	Y	Y	1987-98	six sources cited
liquified petroleum gas (LPG)	Y	Y	1983-93	seven sources cited
fuel oil #2	Y	Y	1983-93	seven sources cited
fuel oil #6	Y	Y	1983-93	seven sources cited
fuel oil #4 [g]	Y	Y	1983-93	seven sources cited

Y: yes, included in inventory.
-- : not included in inventory.
[a] In general, the *Ecobilan* inventories provide descriptions of data quality but often do not report how data were collected (e.g., measured, estimated, etc.). Therefore, information on the data collection method is not presented here.
[b] *Sources*: ETH (EidgenÖssische Technische Hochschule): Data from the ETH (Swiss Federal Institute of Technology) (*Ecobilan,* 1999). FOEFL (Swiss Federal Office of Environment, Forests and Landscape): Data from the Eco-inventory of Packaging published by the Swiss FOEFL; FOEFL is also known as BUWAL, the acronym in German (*Ecobilan,* 1999). Boustead: LCI database developed by Boustead Consulting (*Ecobilan,* 1999).
In general, the geographic boundaries for different sources are as follows: (1) ETH and FOEFL data are from Europe; (2) Boustead data are from Europe and/or the United States; and (3) miscellaneous sources may be European or U.S. data.
[c] The invar inventory is a combination of 36% of the nickel inventory and 64% of the ferrite inventory.
[d] The steel inventory was originally provided by *Ecobilan* without detailed documentation; however, DEAM data that were received later have inventories for several steel production processes. The sources listed here are for the DEAM data.
[e] Boustead addresses transportation; however, the extent to which it is included in a particular process inventory is uncertain.
[f] The styrene-butadiene process is the 50/50 average of the styrene and butadiene processes.
[g] The fuel oil #4 process is the 50/50 average of the fuel oil #2 and fuel oil #6 processes.

2.2.2.2 Electric grids

Several sources of data were consulted to generate the fuel-specific inventories that were used to create the overall electricity generation inventories. Table 2-10 summarizes the data sources and some of the data quality indicators for these inventories. Appendix E discusses the data sources and data quality in detail.

As shown in Table 2-10, the electricity generation data were obtained primarily from secondary sources and include data from the mid-1990s as well as data from an unknown time frame. Most are based on measured data collected by the original source, although some are estimated or the data collection method is unknown. Finally, most of the fuel-specific inventories are based on U.S. data, indicating these data are probably less representative and thus of lower quality when applied to the Japanese electric grid.

Table 2-10. Data sources and data quality indicators for the electric generation inventories

Type of data	Source	Year of publication	Data collection method	Geographic boundaries
Net electricity generation by fuel	U.S. Energy Information Administration (EIA)	1997	Measured	U.S. and Japan
Primary inputs (Fuel)	EIA	1997	Measured	U.S.
Ancillary inputs	EIA, California Energy Commission, utility contacts	Varies	Varies [a]	U.S.
Air emissions	Primarily AP-42 plus other sources [b]	Varies, but mostly AP-42 data from 1995	Varies [a]	U.S.
Water releases	Oak Ridge National Laboratory (ORNL) [c]	1994	Unknown	U.S.
Radioactive air and water releases	ORNL [d]	1995	Measured	U.S.
Solid wastes	ORNL [e]	1994	Unknown	U.S.

[a] Includes emission factors from measured and estimated data, plus data where data collection methods were not reported.
[b] AP-42 is the U.S. EPA's compilation of Air Pollutant Emissions Factors (EPA, 1996).
[c] Coal-fired water release data from ORNL report addressing the externalities of coal fuel cycles (ORNL, 1994).
[d] From ORNL report addressing the externalities of nuclear fuel cycles (ORNL, 1995).
[e] Coal-fired solid waste data from ORNL report addressing the externalities of coal fuel cycles (ORNL, 1994); radioactive solid waste data from ORNL report addressing the externalities of nuclear fuel cycles (ORNL, 1995).

2.2.3 Limitations And Uncertainties

The limitations and uncertainties associated with the upstream materials, fuels, and electricity generation inventories are primarily due to the fact that these inventories were derived from secondary sources and thus are not tailored to the specific goals and boundaries of the CDP. Because the data are based on a limited number of facilities and have different geographic and temporal boundaries, they are not necessarily representative of current industry practices or of industry practices in the geographic and temporal boundaries defined for the CDP (see

Section 1.4). These are common limitations and uncertainties of LCA, which strives to evaluate the life-cycle environmental impacts of entire product systems and is therefore limited by resource constraints which do not allow the collection of original, measured data for every unit process within a product life cycle. Despite these limitations and uncertainties inherent in LCA methodology itself, LCA remains useful and, indeed is increasingly used by industry, governments, and other stakeholders as part of a comprehensive decision-making process or to understand broad or general environmental trade-offs.

2.2.3.1 Upstream material and fuel processes

Because they are derived from secondary sources, the upstream materials and fuels inventories used in the CDP do not precisely meet the geographic and temporal boundaries outlined for the CDP. Some data are from Europe, some from the United States, and some a combination of both. The manufacturing data for this project were collected from companies in the United States, Japan, and Korea (see Section 2.3), and the available upstream data may not represent the exact location or type of processing represented in the upstream data inventories. This is a limitation to using secondary data; however, the upstream data are only one portion of the overall inventory of the product systems being evaluated, and the project partners chose to focus on collecting primary data for the product manufacturing life-cycle stage, since those data had not been previously compiled.

Another limitation of the upstream inventory data is the lack of transportation data for some processes. These data become particularly important when, for example, raw materials are uncommon and must be transported long distances for processing or when the particular transport mode used for a particular material tends to have high environmental impacts. However, the original data sources used in the *Ecobilan* inventories (see Table 2-9) are among the most used LCI databases in the world (*Ecobilan,* 1999), which suggests the lack of transportation data for upstream processes is not unique to the CDP LCI, but a common limitation of other LCIs as well.

2.2.3.2 Electricity generation data

The limitations to the electricity generation inventory data are provided in Appendix E, Section 6. As another limitation, the Japanese grid was chosen when manufacturing data were from more than one country. Appendix E also describes how the U.S. fuel-specific inventories are applied to the Japanese grid, although technologies, efficiencies, etc. used in Japan are likely to differ from those in the United States. Furthermore, U.S. fuel-specific inventories were derived from secondary sources which did not necessarily meet our temporal boundaries, but did meet geographic boundaries for the U.S. inventory.

2.3 PRODUCT MANUFACTURING

2.3.1 Methodology

2.3.1.1 Identification of processes and manufacturers

Through literature research and contacts with industry experts, the manufacturing processes and the component parts of a CRT and an LCD computer monitor were identified. The major manufacturing processes and components, in terms of resources used, and potential importance to environmental impacts, were selected for inclusion in our primary data collection effort.

Once the components and processes were chosen, companies who might supply manufacturing data for the project needed to be identified. In order to identify those manufacturers, the DfE project's Core and Technical Work Groups were consulted. These groups consist of parties interested in the project results and willing to provide technical assistance throughout the project, including identifying contacts in manufacturing facilities. Manufacturing of CRTs, LCDs, and their component parts is done all over the world. Some manufacturers are in the United States; however, most manufacturers of desktop computer monitors and their components are in Asia. Where available, U.S. industry partners provided contacts at U.S. as well as some Japanese manufacturing facilities and questionnaires were sent to those contacts.

To assist in the collection of data in Asia, UT subcontracted with the Asian Technology Information Program (ATIP) to identify company contacts, and to distribute and collect questionnaires from Asian manufacturers. ATIP acted as a liaison between UT and Japanese and Korean companies that participated in the study.

Participation in the study was completely voluntary. Companies were provided with the goals of the study and the potential benefits of their participation. Once a company chose to participate, they were sent data collection questionnaires to complete information about their manufacturing process and to provide their inventory of process inputs and outputs. A copy of the manufacturing data collection questionnaire that was developed for and used in this study is provided in Appendix F.

The manufacturing processes for which primary data were collected are listed below. In parenthesis are the number of individual data sets collected for each process:

CRT monitor:

- CRT monitor assembly (3)
- CRT (tube) manufacturing (3)
- CRT leaded glass manufacturing (3)

LCD monitor:
- LCD monitor assembly (2)
- LCD panel and module manufacturing (7)
- LCD glass manufacturing (1)[2]
- color filter patterning on front glass (1)
- liquid crystal manufacturing (2)
- polarizer manufacturing (1)
- backlight unit assembly (3)
- backlight light guide manufacturing (1)
- cold cathode fluorescent lamp (CCFL) manufacturing (1)

How these processes are linked to one another in the CRT and LCD life-cycles is presented in Figures 2-2 and 2-3, respectively. The companies that provided data for the foregoing processes are listed in Table 2-11.

Table 2-11. Companies that provided primary manufacturing data for the CRT and/or LCD

Company	Technology	Company	Technology
American Video Glass Company	CRT	Nippon Denyo Co., Ltd.	LCD
T. Chatani and Co., Ltd.	LCD	Nippon Electric Glass Co., Ltd.	CRT
Chisso Corporation	LCD	Polaroid Corporation	LCD
Eizo Nanao Corporation	CRT, LCD	Samsung Electronics	LCD
Harison Electric Co., Ltd.	LCD	Sharp Corporation	LCD
Hoshiden and Philips Display Corporation	LCD	Sony Corporation (Japan)	CRT
Hyundai Electronics Industries Co., Ltd.	LCD	Sony Electronics Inc. (U.S.)	CRT
Iiyama Electric Co., Ltd.	CRT, LCD	Stanley Electric Co., Ltd.	LCD
Matsushita Electric Industrial Co., Ltd.	LCD	Techneglas	CRT
Merck Japan Ltd.	LCD	Toppan Printing Co., Ltd.	LCD
Mitsubishi Electronic Co., Ltd.	LCD	Toshiba Display Technology Co., Ltd.	CRT, LCD

Another process that was included in the CRT manufacturing stage data was frit manufacturing. We were not able to obtain primary data for this process; therefore, secondary data were collected from EPA documentation and personal contacts (see Appendix G). An inventory for printed wiring boards (PWBs) was also developed and included in the manufacturing stage analysis. The PWB inventory is based on manufacturing of the electronic boards, and does not include the components on the PWBs. The PWB data were obtained from an industry representative who was able to provide general data not necessarily from one facility, but from a combination of facilities, based on his experience (Sharp, 2000). More details about PWB data collection are provided in Appendix G.

[2] LCD glass manufacturing data were derived from the three sets of CRT leaded glass manufacturing data (modified to remove lead from the inventory).

The manufacture of some components were not included in the scope of this study because they were either deemed to be of less significance to the overall product inventories, or data could not be obtained. However, all components were included as part of the final assembled monitor even when individual manufacturing inventories were not. For the CRT, the manufacture of the electron gun, deflection yoke, and phosphors were not included as separate processes, and for the LCD, the transistor metals/materials, spacers, drivers/driver ICs, and color filters were not included.

2.3.1.2 Data collection questionnaires

Data collection questionnaires were developed by the UT research team and approved by the Technical Work Group to most efficiently collect inventory data needed for the LCA. Appendix F provides a copy of the questionnaire given to product and component manufacturers. The data that were collected include brief process descriptions; primary and ancillary material inputs; utility inputs (e.g., electricity, fuels, water); air, water and waste outputs; product outputs; and associated transportation. Quantities of inputs and outputs provided by companies were converted to mass per unit of product. Transport of materials to and products or wastes from the manufacturing facility were also reported. Details of the transportation analysis for this project are presented in Section 2.6.

A total of 27 product manufacturing questionnaires were collected for 11 different processes. The corresponding countries and the number of data sets from each country are listed in Table 2-12.

Table 2-12. Location of companies and number of process data sets

Process	Country of origin of data (# of data sets)
CRT monitor assembly	Japan (2), U.S. (1)
CRT (tube) manufacturing	Japan (2), U.S. (1)
CRT leaded glass manufacturing	Japan (1), U.S. (2)
CRT frit manufacturing	generic secondary data from the U.S.
LCD monitor assembly	Japan (2)
LCD panel and module manufacturing	Japan (5), Korea (2)
LCD - glass manufacturing	Japan and U.S. (1)*
LCD - color filter patterning on front glass	Japan (1)
LCD - liquid crystal manufacturing	Japan (2)
LCD - polarizer manufacturing	Japan (1)
LCD - backlight unit assembly	Japan (3)
LCD - backlight light guide manufacturing	Japan (1)
LCD - cold cathode fluorescent lamp (CCFL) manufacturing	Japan (1)
PWB manufacturing (for CRT and LCD monitors)	generic secondary data from the U.S.

* Average of three data sets for CRT leaded glass manufacturing modified to remove lead from the inventory.

2.3.1.3 Allocation

Data provided by manufacturers may need to be allocated to the products of interest (i.e., 17" CRT or 15" LCD) in three situations:

- data are provided for more than the defined functional unit;
- data are provided on a rate basis instead of per functional unit (product); and
- data are provided for monitors/components of more than one size (i.e., not only 17" CRTs or 15" LCDs).

In some cases, allocation was not required, as the inventory data collected were for one unit of the product, defined as the functional unit. The three cases where allocation was necessary are briefly described below.

In the first case, simple scaling was required when data were provided for all 17" CRT or 15" LCD monitors produced at a plant, as opposed to only one monitor. This simply requires dividing the inventory mass by the number of monitors produced.

In the second case, data were provided over a certain amount of time. The inventory data were then scaled to represent the functional unit. For example, if it was reported that *x* kilograms of a material are used *per year* to produce one 17" or 15" monitor, and *y* number of products are produced per year, then the amount of that material per functional unit is *x*/*y*.

In the third situation, allocation was also necessary for a company that manufactured more than just the product or component of interest for this study. For example, a monitor manufacturer may assemble various sized monitors, in addition to 15" LCDs or 17" CRTs. Therefore it was necessary to allocate the process inventory to only our product of interest. We used the difference in mass between the product of interest and other co-products and the difference in the number of each product produced to allocate the inventory to the functional unit.

2.3.1.4 Aggregating manufacturing data

After one set of data from one company is allocated to one monitor, processes for which we collected more than one company's data were averaged together. Once the inventory data for a process were averaged, the electricity consumption from that process was linked to the appropriate electric grid inventory (i.e., Japanese or U.S.). All the manufacturing processes were linked to the Japanese grid, with the exception of frit and PWB manufacturing, both of which were based on data collected in the United States. Where process data were represented by companies in more than one country, the countries in which the majority of facilities were located was used for the basis of which electric grid to use. An exception is the polarizer data, which was from the United States, but the manufacturing was only a pilot plant and not producing a product in the open market. Therefore, it was assumed that polarizer manufacturing, as with most other LCD components, was done in Japan. Once each manufacturing process inventory for each monitor type was complete (i.e., an averaged inventory with an associated electric grid), each was aggregated with the rest of the manufacturing stage processes to comprise the inventory for the manufacturing stage for a monitor. This manufacturing stage inventory was then combined with the other life-cycle stages to represent the full LCI for each monitor type.

2.3.2 Data Sources and Data Quality

While manufacturers worldwide were offered the opportunity to participate in this project, only manufacturing data from Japan, Korea, and the United States were collected. The quality of the data can be evaluated against two factors: (1) the date of the data; and (2) the type of data (i.e., measured, calculated or estimated). An understanding of how data were collected and data verification steps should also be considered when evaluating the data quality. The data collection phase of this project began in 1997 and extended through 2000. Some processes are more sensitive to production dates than others. Most processes included in this analysis are mature technologies and are not expected to differ significantly between the years 1997 and 2000. However, an exception is LCD panel manufacturing, which is an evolving and rapidly advancing process and has seen changes between these years. The countries and dates from which data for each process were obtained are presented in Table 2-13. For the LCD panel and module manufacturing process, most data were from 1998 and 1999.

In the data collection questionnaires, companies identified whether the quantity of each inventory item was a measured, calculated, or estimated value. These identifiers were referred to as the "data quality indicator" (DQI) in the manufacturing questionnaire. The breakdown of DQIs for the inventory items in the CRT and LCD processes are presented in Tables 2-14 and 2-15, respectively. The last line in each table shows overall averages weighted by the number of inventory items in each data set. For the CRT, 43% of the data were measured, 34% calculated, 13% estimated, and 10% were not classified. For the LCD, a similar distribution shows 33% measured, 30% calculated, 23% estimated, and 14% not classified.

Table 2-13. Applicable years of primary data sets

Process	# of data sets	Dates of inventory for each data set
CRT monitor assembly	3	1997, 1998-9, 1999
CRT (tube) manufacturing	3	1997, 1998, 1998
CRT leaded glass manufacturing	3	1998, 2000, 2000
LCD monitor assembly	2	1998, 1999
LCD panel and module manufacturing	7	1997-8, 1998, 1998, 1998-9, 1999, 1999, 1999-2000
LCD - color filter patterning on front glass	1	1998
LCD - glass manufacturing*	1	1998-2000
LCD - liquid crystal manufacturing	2	1998, 1998
LCD - polarizer manufacturing	1	1997
LCD - backlight unit assembly	3	1998, 1999, 1999
LCD - backlight light guide manufacturing	1	1999
LCD - cold cathode fluorescent lamp (CCFL) manufacturing	1	1998-9

* Primary data, but developed from the CRT glass manufacturing data.

Data quality can also be reviewed in terms of data collection methods. Much effort was given to collecting primary data from manufacturers in this study. Questionnaires were sent out and follow-up communication was conducted to verify data gaps or discrepancies. Twelve companies were visited directly to clarify data and telephone or electronic communication followed-up those and the remaining companies that were providing data for the study. Where data could not be confirmed, additional literature research and discussions with other industry experts were conducted.

Table 2-14. Data quality indicator percentages for the CRT processes

Process	**% of inventory items that are:**			
	Measured	**Calculated**	**Estimated**	**Not reported**
CRT monitor assembly				
Data set 1 (22 inventory items)	9%	64%	27%	0%
Data set 2 (11 inventory items)	9%	83%	0%	9%
Data set 3 (33 inventory items)	3%	0%	0%	97%
total inventory items = 66	wt. avg = 6%	wt. avg = 35%	wt. avg = 9%	wt. avg = 50%
CRT (tube) manufacturing				
Data set 1 (69 inventory items)	91%	1%	4%	3%
Data set 2 (51 inventory items)	45%	55%	0%	0%
Data set 3 (83 inventory items)	21%	78%	1%	0%
total inventory items = 203	wt. avg = 51%	wt. avg = 46%	wt. avg = 2%	wt. avg = 1%
CRT leaded glass manufacturing				
Data set 1 (43 inventory items)	9%	3%	86%	2%
Data set 2 (45 inventory items)	91%	7%	0%	2%
Data set 3 (2 inventory items)	100%	0%	0%	0%
total inventory items = 90	wt. avg = 52%	wt. avg = 5%	wt. avg = 41%	wt. avg = 2%
Overall weighted average for CRT (359 items)	**43%**	**34%**	**13%**	**10%**

Table 2-15. Data quality indicator percentages for the LCD processes

Process	% of inventory items that are:			
	Measured	**Calculated**	**Estimated**	**Not reported**
LCD monitor assembly				
Data set 1 (36 inventory items)	5%	78%	17%	0%
Data set 2 (10 inventory items)	10%	80%	10%	0%
total inventory items = 46	wt. avg = 6%	wt. avg = 78%	wt. avg = 16%	wt. avg = 0%
LCD panel and module manufacturing				
Data set 1 (71 inventory items)	80%	17%	0%	3%
Data set 2 (39 inventory items)	0%	100%	0%	0%
Data set 3 (45 inventory items)	40%	32%	17%	11%
Data set 4 (139 inventory items)	55%	38%	0%	7%
Data set 5 (53 inventory items)	43%	0%	36%	21%
Data set 6 (86 inventory items)	0%	0%	24%	76%
Data set 7 (32 inventory items)	0%	0%	97%	3%
total inventory items = 465	wt. avg = 37%	wt. avg = 26%	wt. avg = 17%	wt. avg = 20%
LCD - glass manufacturing* (83 inventory items)	0%	0%	100%	0%
LCD - color filter patterning on front glass (29 inventory items)	97%	0%	3%	0%
LCD - liquid crystal manufacturing				
Data set 1 (41 inventory items)	22%	64%	7%	7%
Data set 2 (6 inventory items)	0%	0%	0%	100%
total inventory items = 47	wt. avg = 19%	wt. avg = 56%	wt. avg = 6%	wt. avg = 19%
LCD - polarizer manufacturing (30 inventory items)	57%	17%	20%	6%
LCD - backlight unit assembly				
Data set 1 (20 inventory items)	0%	90%	0%	10%
Data set 2 (12 inventory items)	50%	0%	8%	42%
Data set 3 (12 inventory items)	0%	92%	8%	0%
total inventory items = 44	wt. avg = 14%	wt. avg = 66%	wt. avg = 4%	wt. avg = 16%
LCD - backlight light guide manufacturing (5 inventory items)	40%	40%	20%	0%
LCD - cold cathode fluorescent lamp (CCFL) manufacturing (36 inventory items)	58%	39%	0%	3%
Overall average for LCD (785 items)	**33%**	**30%**	**23%**	**14%**

* Data based on CRT leaded glass manufacturing data.

2.3.3 Limitations and Uncertainties

The limitations and uncertainties associated with the manufacturing stage are related to the following categories:

- the product system boundaries (scope),
- the data collection process, and
- the data.

Specific limitations/uncertainties for each of these categories are briefly described below.

2.3.3.1 Product system boundary uncertainties

The scope of the analysis included the major monitor components; however, it excluded certain components, such as column and row driver ICs for the LCD and the electron gun for the CRT. The components that were thought to possibly have an effect on the inventory were the column and row drivers, as IC manufacturing is known to be energy intensive and use various process chemicals. Based on some back-of-the-envelope calculations, the exclusion of the manufacturing of the column and row driver ICs is not expected to have a large impact on the inventory or impact results due to the small size of the drivers. Therefore, it is assumed that the exclusion of the column and row drivers will not have a significant impact on the study results.

The scope of the analysis in this study was also dependent on whether companies were willing to provide data. LCD glass manufacturing data from a primary source are not included in the inventory because no companies were willing to supply the data. For example, one manufacturer chose not to provide data because LCD glass manufacturing technology is still developing and is expected to improve from current low yields and high waste generation. However, because glass is an important component by weight of the LCD, we chose to modify the CRT glass manufacturing data to represent LCD glass manufacturing.

Both CRT and LCD glass are considered to be "specialty glasses" in the glass industry and a limited number of companies produce these products. Consequently, there are limited public data available on the production of these glasses. (One major difference between the CRT glass and the LCD glass is that CRT glass contains lead oxide while LCD glass does not.) Therefore, the primary data collected for this study for CRT glass manufacturing was modified by removing inputs and outputs containing lead, and used to represent LCD glass manufacturing. The remaining inputs and outputs were assumed to be the same per kilogram of glass produced. Further research was conducted to confirm whether this was a valid assumption for the energy used in production. Consultation with experts in the field revealed differing estimates between energy used to produce a kilogram of CRT glass and a kilogram of LCD glass. Estimates ranged from an equal amount of energy per kilogram for CRT and LCD glass production, to twice as much energy per kilogram of LCD glass compared to CRT glass. With an assumption of equal or greater energy use for the LCD (call that quantity of energy X), the proportion of that energy (X) that is electrical energy and fuel energy was assumed to be the same as that given in the primary data for CRT glass production (if the portion of energy X for the CRT was 30% electrical and 70% fuel energy, those same proportions were used for the LCD's breakdown of energy X).

Uncertainty in the differences between energy used for CRT versus LCD glass production are related to production yield and melting point. The melting point of LCD glass is greater than that of CRT glass; however, the difference in the production yield is uncertain compared to the difference in melting point. The production yield for CRT and LCD depends on whether one considers the surface area or the volume of the glass. LCD glass is a flat glass product and excess glass is cut off the ends to obtain the final product. CRT glass manufacturing drops molten glass into a mold and glass is not cut off of a flat piece of glass as in LCD production, but excess glass may be produced during the molding process. Another factor in the difference in energy used for CRT and LCD glass is that the LCD glass must meet high specification standards for use as a substrate for the transistors to be patterned on the glass. Additional finishing steps are required and the process is conducted in clean rooms (described in Section 1.3.3.2, LCD manufacturing). The assumption that the same amount of energy is used for CRT glass and LCD glass production takes into account each of these factors. The baseline analysis in this study assumes the energy use per kilogram of LCD glass is equivalent to that of CRT glass. The uncertainty associated with the glass manufacturing data is a limitation to the manufacturing inventory data set. Additional limitations from the glass manufacturing data are discussed below with other "data uncertainties" in Section 2.3.3.3.

2.3.3.2 Data collection process uncertainties

Limitations and uncertainties related to the data collection process include the fact that companies were self-selected, which could lead to selection bias (e.g., those companies that are more advanced in terms of environmental protection might be more willing to supply data than those that are less progressive). Also, the data were supplied by companies whose vested interest is to have their product look more desirable, which could result in biased data being provided. However, multiple sets of data were obtained for this project, where possible, so that average processes could be developed in an attempt to avoid biased data. The peer review process and employment of the Core and Technical Work Groups as reviewers in this project is intended to help reduce or identify any such bias. Further, several companies were visited and contacted for verification of data.

Other data collection-process limitations resulted from the difficulty in obtaining and verifying data over long distances (i.e., Japan and Korea to United States) as well as from the language barrier. The use of ATIP as the Asian Liaison aided in reducing this limitation; however, there were still language barriers that had to be overcome with ATIP, as well as through direct communication with several companies.

2.3.3.3 Data uncertainties

Additional limitations to the manufacturing stage inventory are related to the data themselves. Several attempts were made to verify or eliminate outliers in the data; however, uncertainty in some data remained due to large data ranges and outliers. Specific data with the greatest uncertainty include: (1) CRT glass manufacturing energy inputs (mentioned above in Section 2.3.3.1); (2) the distribution of fuel/electricity inputs for LCD module manufacturing; and (3) the use of a large amount of liquified natural gas (LNG) as an "ancillary material" and not a fuel.

In addition to the uncertainty in the difference between energy used to manufacture CRT glass and LCD glass, the energy reported to produce a kilogram of CRT glass varied greatly between the data sets. Consultation with experts in the glass industry confirmed that the average energy consumption derived from the primary data sets, although it appeared to be high, could be possible. The total energy inputs per kilogram of glass from the primary data sets used in the analysis, ranged over a factor of approximately 150 (i.e., the largest total energy value in the data was about 150 times that of the smallest value). Due to this large discrepancy, the glass energy data is the subject of sensitivity analyses in this study. The high energy use values were mostly a function of liquified petroleum gas (LPG) used as a fuel.

Other data for which large ranges were found, and which could be important to the results, are the energy use from LCD panel/module manufacturing. Energy data were provided by six of the seven companies supplying LCD panel/module data. The percent of energy from electricity ranged from approximately 3% to 87%. Three of the companies had the electrical energy component contributing greater than 50% of the total energy use, and the other three companies listed other fuels [e.g., LPG, LNG] as contributing greater than 50% to the total energy use. Another large discrepancy was the total energy use for panel/module manufacturing. Four of the six companies had energy use per panel between approximately 440 MJ/panel and 940 MJ/panel, while the two remaining companies had approximately 4,100 and 7,000 MJ/panel. The average per panel was approximately 2,270 MJ/panel and the standard deviation was about 2,910 MJ/panel.

Given the wide variability in the data and large standard deviation, CDP researchers evaluated the data for outliers by breaking the total energy data points into quartile ranges. Minor outliers are then those within a certain range of multipliers beyond the middle 50% of the distribution. That is, the interquartile range (IQR) (i.e., the range of values representing the middle 50%) multiplied by 1.5 is the lower bound of the minor outlier and the IQR multiplied by three is the upper bound. Anything beyond the IQR times three is a major outlier. Using this approach, one data set was found to be a minor outlier and another was found to be a major outlier. These outliers were excluded from the averages used in the baseline analysis, but included in the averages used in a sensitivity analysis (see Section 2.7.3.3).

Finally, the average amount of LNG used as an ancillary material (not a fuel) in LCD panel/module manufacturing was reported as 194 kg per functional unit. This data point remained in the inventory data set for LCD manufacturing, and was assumed to indeed be an ancillary material, and not a fuel. LNG was also reported as a fuel as a separate input (approximately 3.22 kg/functional unit). Keeping the LNG ancillary material in the inventory will not affect the energy impact results, since LNG used as an ancillary material is only linked to the production of that material, and not to the use of it as a fuel. It will, however, affect upstream impacts from the production of the material. Note that the natural gas process was used as a surrogate for the production of LNG, as inventory data was not available for the latter.

2.4 PRODUCT USE

2.4.1 Methodology

The methods for developing the use stage inventory are presented in Appendix H and summarized here. CRTs and LCDs use different mechanisms to produce images on screen, which result in different energy use rates. These energy use rates (e.g., kW) can be combined with the time a desktop monitor is on during its lifespan (hours/life) to calculate the total quantity of electrical energy consumed during the use life-cycle stage (e.g., kWh/life). In this project, two lifespan scenarios are considered:

- *Effective life* - the actual amount of time a monitor is used, by one or multiple users, before it is disposed of, recycled, or re-manufactured. Reuse of a monitor by a subsequent user is considered part of its effective life. Recycling, on the other hand, is the reuse of parts or materials that require additional processing after disassembly, and it is not considered part of the use stage.
- *Manufactured life* - the amount of time either an entire monitor or a single component will last before reaching a point where the equipment no longer functions, independent of user choices.

These two scenarios are considered in this project in order to account for potential differences between how consumers *currently* use the equipment and how consumers could use the equipment. Currently, consumers often replace monitors before they physically break down. This behavior results in a lifespan that is not solely dependent on the monitor technology itself. The manufactured life, on the other hand, is based on the technology and represents how consumers could potentially use the equipment. If the lifespans are significantly different, the difference could have a large impact on how the use stage compares to the other life-cycle stages in this study. The baseline analyses in this project use the effective life scenario and the manufactured life will be part of the sensitivity analyses.

2.4.1.1 Energy use rate

Most desktop monitors manufactured today are built to use several different power consumption modes during normal operation. There are often up to four different power consumption modes that can be used by a monitor in going from a state of active use to a state of almost complete shut-down. These four modes, from greatest power consumption to least, are typically entitled “full-on” or active use, “standby,” “suspend,” and “active-off.” For this report, manufacturers’ data on these power modes were collected from company contacts and Internet sites for 35 different 17" CRT monitors and 12 different 15" LCD monitors. The complete list of these data is presented in Appendix H, Attachment A, Table A1.

For the purposes of this study, the power consumption modes have been categorized into two modes: “full-on” and “low.” The “low” power mode is an average of the three low power modes typically provided by the manufacturers (i.e., standby, suspend, and active-off). These three categories were averaged to create one “low” power consumption mode because hours per use data (needed for calculations in this study) are only available for a “full-on” and a reduced power mode. The low mode value for the CRT is the average of the three modal averages of standby, suspend, and active-off. For the LCD, data on only two low-power modes (standby and active-off) were provided by manufacturers (see Appendix H, Attachment A, Table A2), and therefore, the low mode value is an average of those two modal averages. Table 2-16 presents the average values for full-on and low power modes that were used for subsequent calculations in this analysis.

Table 2-16. Average energy use rates [a]

Monitor type	Full-on power mode [kilowatts (std. dev.)]	Low power mode [b] [kilowatts (std. dev.)]
17" CRT	0.113 (0.015 SD)	0.013 (0.005 SD)
15" LCD	0.040 (0.007 SD)	0.006 (0.003 SD)

[a] See Appendix H, Attachment A, Table A1 for source data.
[b] An average of company-reported values for standby, suspend and active-off (see Appendix H, Attachment A, Table A1).
Note: 1 kW = 1000 Watts = 1000 J/sec.

2.4.1.2 Effective life (baseline lifespan calculation)

The effective life scenario attempts to model the actual quantity of hours that an average monitor spends in each of the two primary power consumption modes (full-on and a lower power state) during its lifetime. The effective life of an average monitor is based on the following information:

- the proportion of computers that are used in an office environment versus a home environment, to account for different use rates in these two basic user environments;
- the amount of time in a year a typical monitor spends in full-on power mode and in a lower power-consuming mode for both office and home environments; and
- the number of years a typical monitor is used during its lifespan for both office and home environments, not including years in storage before a monitor is replaced or discarded (as it is not consuming power during storage).

Under the effective life scenario, we assume there is no difference in the amount of time a CRT or LCD monitor is operating. That is, the hours per life for the effective life calculation is not technology-dependent. Therefore, the same set of hours-per-life values are used to calculate the kWhs used per effective lifetime for a CRT and an LCD. The remainder of this section discusses the data and methods used to calculate the hours-per-life values used in the effective life scenario. More details are also provided in Appendix H.

Percentages of Office- and Home-Environment Users

Home and office users of computer equipment do not follow the same use patterns. Thus, data are needed on the percent of users in each environment to determine the use pattern of an “average” computer monitor. It is assumed that 65% of computers are in office environments and 35% in home environments, based on data available through the Computer Industry Almanac (CIA, 1997) and the Energy Information Administration (EIA, 1999b) (see Appendix H, Section 2.2.2.1 for more details).

Note that an “office” environment may be a school, hospital, or other commercial environment, and the computers they use may follow widely varying degrees of use. For example, computers (and thus monitors) in a school may only be used a few hours in a day, while hospitals might operate theirs nearly constantly. For this study, it is assumed that on average, typical office use patterns (to be presented below, and in Appendix H, Section 2.2.2.2) are representative of all non-home environment users.

Operating Pattern (average hours in use per year)

In order to determine the amount of electricity consumed during a monitor’s effective life, we need to know the use operating patterns for both the office and home environments. The “operating pattern” is defined here as the number of hours per year spent in each power mode. The average number of hours per mode per year will be the weighted average of the two user environments (i.e., 65% office, 35% home).

A literature search for computer monitor operating patterns was conducted for both office and home environments and a summary of literature reviewed is presented in Appendix H, Attachment A, Table A3. Based on the literature (Nordman *et al.,* 1996, Fanara, 1999, EIA, 1999b) and other assumptions presented in Appendix H, Section 2.2.2.2, we assume the number of hours per year that office and home monitors are used in each mode are as follows:

- Office:

Full-on power mode:	1,095 hrs/yr
Low power mode:	2,263 hrs/yr
Total:	3,358 hrs/yr

- Home:

Full-on power mode:	522 hrs/hr
Low power mode:	793 hrs/yr
Total:	1,315 hrs/yr

Average Years Per Life

The number of years per life, multiplied by the operating patterns in hours per year (listed above), will result in the hours per effective life. A monitor may be reused in multiple “lives” before reaching its end-of-life. The end-of-life is defined as the point at which the monitor is no longer used for its intended purpose in the physical form in which it was originally manufactured. End-of-life options include indefinite storage (in which case it is not reused after storage), de-manufacturing, recycling, or disposal. A monitor may be stored before being reused; however, this storage time will not affect our use calculations since no electricity is required to operate the monitor during this storage. After its first life as used by the original owner, a monitor might be used by different people and with different PC systems in subsequent lives.

For data on the number of years of use that are in a monitor’s lifetime, several sources of information were reviewed (see Appendix H). Based on a recent study by the National Safety Council (NSC, 1999), we assumed that a monitor is used for 4 years in its first life and 2.5 years for its second or subsequent lives. The operating patterns (in hours/year) presented above are assumed to be the same for all of the 6.5 years of the total effective life. However, in the lives subsequent to the first life, the hours per year values are reduced by the fraction of monitors assumed to be reused. Matthews *et al.* (1997) estimated that 45% of PCs are reused after a first life; thus, the effective life operating pattern values in years of life after the first life are 45% of the values in the first life.

Lifespan estimates from the National Safety Council (NSC, 1999) were specific to CRT monitors; however, they were not specific to LCD desktop monitors. The NSC data did contain estimates of a "Notebook PC," which were two to three years for the first life and one to two years for the remaining lives; however, we expect that desktop LCD monitors will more closely mirror the lifetime estimates of a desktop CRT monitor than that of a notebook PC. Consequently, it was assumed that LCD desktop monitors also spend four years in their first life and 2.5 years in their subsequent lives. Additionally, the NSC document did not attempt to separate those computer systems or monitors that are used in an office versus a home environment. Thus, it was assumed that the same years per life are realized for office and home environments.

Effective Life Estimates (hours per life)

The data presented above are summarized in Table 2-17 and used to estimate the total hours per effective life. The values for hours per year per power mode are assumed to be the operating pattern throughout the first life (first four years). In the remaining lives, the annual operating hours decrease to 45% of the hours in operation during each year in the first life, with the remaining lives lasting a total of 2.5 years. Table 2-17 also presents the total hours per effective life per mode, based on percentage in office and home environments. These values are in bold in Table 2-17 (4,586 and 8,961 hrs per effective life) and will be multiplied by the energy use rates per mode (presented in Table 2-16), to calculate the total energy consumption per effective life for each monitor type.

Table 2-17. Effective life values

User environment	Power mode	First life (4 years)		Remaining lives (2.5 years)		Model totals [b] (hr/effective life)
		Operating pattern (hr/yr)	Total (hr/4 yrs)	Operating pattern (hr/yr) [a]	Total (hrs/2.5 yrs)	
Office (65%)	Full-on	1,095	4,380	493	1,233	5,613
	Low	2,263	9,052	1,018	2,545	11,597
Home (35%)	Full-on	523	2,092	235	588	2,680
	Low	793	3,172	357	893	4,065
Weighted average [c]	Full-on	---	---	---	---	**4,586**
	Low	---	---	---	---	**8,961**

[a] The remaining lives operating pattern is 45% of first life operating pattern, based on 45% of monitors that are reused (Matthews *et al.*, 1997).
[b] Modal totals calculated as [(Total for first 4 years) + (Total for remaining 2.5 years)].
[c] The weighted averages shown for full-on and low power modes are based on the assumption that 65% of users operate in an office environment and 35% operate in a home environment.

Effective Life Total Energy Consumption (kWh/life)

In order to calculate the total kWhs consumed, first, the energy use rates (kW) were multiplied by the lifespans (hours per life) for each mode and each monitor type. They were then summed for the two power modes to obtain a total kWh/life for each monitor type (Table 2-18).

Table 2-18. Effective life electricity consumption

Monitor type	Power mode	Energy use rate (kW)	EL calculated lifespan (hours/life)	EL energy consumption (kWh/life)
17" CRT	Full-on	0.113	4,586	518
	Low	0.013	8,961	116
	Total	----	13,547	634
15" LCD	Full-on	0.040	4,586	183
	Low	0.006	8,961	54
	Total	----	13,547	237

2.4.1.3 Manufactured life (alternative lifespan calculation)

Due to the uncertainty and assumptions associated with the effective life scenario, an alternative scenario is also considered. The manufactured life is defined here as the length of time a monitor is designed to operate effectively for the user. It is the number of hours a monitor would function as manufactured, and is independent of user choices or actions. One way to estimate this manufactured life is to use the mean-time-before-failure (MTBF) specification of a monitor or its components. The CRT MTBF specification dictates the amount of time the display must operate before it reaches its brightness “half-life,” or the ability to produce 50% of its initial, maximum brightness. The MTBF value, generally provided in total hours per life of a monitor, is what most final manufacturers or assemblers of personal computer (PC) equipment, including monitor assemblers, typically specify for a component. To meet the specification, suppliers typically calculate the MTBF (a military-based specification) based on component data. Suppliers’ test results are usually called the “calculated” MTBF. The MTBF value also depends on which combination of power modes are used during testing, which is referred to as the “duty cycle” and each supplier may use a different duty cycle to test their component.

Additionally, monitor assemblers will often perform their own testing, typically entitled “demonstrated” MTBF. The testing includes sequences where the monitor is “stressed” by quickly switching back and forth from an all black picture to an all white one, or quickly switching individual pixels either on and off or through multiple colors or black and white. Manufacturers typically find that their demonstrated MTBF is on the order of twice as long as the calculated MTBF (McConnaughey, 1999; Douglas, 1999). However, it should be noted that the demonstrated MTBF is not a real-time testing method, as the testing data is used in a complex equation to calculate that “demonstrated” value.

From review of the information obtained on CRT-based monitors (see Appendix H, Attachment A, Table A2), it appears that the CRT (the tube) itself is the limiting component, or the component that 99% of the time determines whether the entire monitor has reached its end-of-life. Thus, from the limited information that was obtained on CRTs, and the limited confidence that can be instilled in those data, an average of the two ranges obtained on the estimated lifetime of CRTs (10,000 and 15,000 hours) was used as the CRT manufactured lifetime (12,500 hours) (Goldwassar, 1999; Douglas, 1999).

For active matrix LCDs, the components that have the greatest potential to fail first are the display panel itself (including the liquid crystals and thin-film transistors), backlights, driver integrated circuit (IC) tabs, and other smaller components. The backlights and driver IC tabs can be field-replaced, thus their failure does not necessarily represent the end of the monitor's life. However, failure of the liquid crystals or transistors, which would require replacement of the display panel itself, would most likely mean that the monitor cannot be cost-effectively repaired. The MTBFs of all these components appear to have a broad range. For example, different backlight manufacturers reported from as few as 15,000 hours to as many as 50,000 hours (Douglas, 1999; Tsuda, 1999; VP150, 1999). However, it appears that those components that are not field-replaceable (e.g., the LCD panel) have MTBFs in the range of 40,000 to 50,000 hours (Tsuda, 1999; Young, 1999). Thus in this study, the amount of time an LCD monitor would operate during its manufactured life is assumed to be the average of the two non field-replaceable values, or 45,000 hours. In order for a monitor to operate for 45,000 hours, any major field-replaceable parts that have MTBFs less than 45,000 hours will need to be accounted for in this LCA project. For example, assuming the backlights last on average 32,500 hours (the average of the values obtained for backlights), more than one (approximately 1.4, on average) would be needed for every panel during its lifetime. Therefore, in the final CDP LCA, the manufacturing of extra backlights would need to be included in the inventory.

Little information is available on the duty cycles that component manufacturers use to test components. Thus, it is assumed that the average duty cycle used in testing components is 50% of the time tested in full-on mode and 50% in a lower power mode. Table 2-19 shows the values that are used in this study for the hours per manufactured life for the CRT and LCD. Some sensitivity analyses were done and presented in Socolof *et al.* (2000).

Table 2-19. Manufactured life values

Monitor type	Total hours (hours/life)	Mode	Duty cycle (% time spent in each mode during testing)	Hours per mode (hours/life)
17" CRT	12,500	Full-on	50%	6,250
		Low	50%	6,250
15" LCD	45,000	Full-on	50%	22,500
		Low	50%	22,500

To calculate the manufactured life electricity consumption (kWh/life), the energy use rate (kW) is multiplied by the lifespan (hours/life) for each monitor in each power mode (Table 2-20). The LCD manufactured life (45,000 hours) is 3.6 times greater than the CRT manufactured life (12,500 hours). In an LCA, comparisons are made based on functional equivalency. Therefore, if one monitor will operate for a longer period of time than another, impacts should be based on an equivalent use. Therefore, based on equivalent use periods, 3.6 CRTs would need to be manufactured for every LCD. This will be incorporated into the profile analysis for the comparative manufactured life LCA.

Table 2-20. Manufactured life electricity consumption

Monitor type	Power mode	Energy use rate (kW)	ML calculated lifespan (hours/life)	ML energy consumption (kWh/life)
17" CRT	Full-on	0.113	6,250	706
	Low	0.013	6,250	81
	Total	----	12,500	787
15" LCD	Full-on	0.040	22,500	900
	Low	0.006	22,500	135
	Total	----	45,000	1,035

2.4.1.4 Effective life versus manufactured life

For the CRT monitor, the effective life total hours are 13,547 versus the manufactured life total of 12,500. While this suggests that a CRT can be used longer than is physically possible, it simply reveals our low confidence in these numbers and some of their supporting values, with less confidence in the manufactured life data than the effective life estimates. A more complete discussion of the data quality is presented in Section 2.4.2 and Appendix H.

Assumptions were required several times that could bias these numbers in either direction; however, it is thought that the manufactured life estimate is most likely low based on the other estimates for the overall CRT monitor (see Appendix H, Attachment A, Table A2). However, there was no sound basis for assuming a lower value and thus the above hours per life values were used. It should also be stated that while these numbers are different, they are within an 8% error range of one another, and can be taken to be a near 1:1 ratio, indicating a similar potential lifespan.

For LCDs, the comparison across lifespan scenarios is more consistent with what one would expect, with the manufactured life value of 45,000 hours per life being much greater than the effective life value of 13,547 hours per life. The effective life value reflects the assumption that a user's use habits are not technology-dependent, and would seem to reveal that LCDs are not being used as long as they can physically be (less than a third as long).

The difference between the effective and manufactured lives are important when evaluating all the life-cycle stages for a particular monitor type. If the manufactured life is significantly greater than the effective life, the use stage will have greater impacts, as compared to other life-cycle stages. Therefore, it is important to focus on the lifetime scenario that is most realistic, while still recognizing the potential impacts from another feasible lifespan scenario.

In this project, we will use the effective life as the primary basis for the use stage inventory due to the fact that the effective life data are attempting to obtain a more realistic value for electricity consumed per lifetime, and that we currently have greater confidence in those data versus the manufactured life data. The manufactured life data will be used in one sense as a sensitivity analysis and to discuss potential differences in the use stage impacts based on this alternative lifetime scenario.

2.4.2 Data Sources and Data Quality

Source and quality information for the use stage data are detailed in Appendix H, Table 11. We assigned four categories of data quality ratings: excellent, average, poor, and unknown. In general, data assigned higher quality ratings were directly measured and represent 1998 data. As data required more calculation or estimation, or were found from a previous year, the data quality rating was reduced.

The overall level of use stage data quality is between average and excellent (Appendix H, Table 11). However, a distinct difference can be seen in the average data quality ratings given to manufactured life data (average) and the effective life data (excellent). This implies that greater confidence can be placed in the effective life data than in the manufactured life data. Additionally, the energy use rate data appears to be of average quality.

2.4.3 Limitations and Uncertainties

Details of the limitations and uncertainties associated with the energy use rate, the effective life, and the manufactured life estimates are presented in Appendix H, Section 5.

2.5 END-OF-LIFE

2.5.1 Methodology

A Technical Memorandum, attached as Appendix I, was prepared for this project that provides background on the EOL issues for the CRT and LCD. It also provides details on the methodology used in this project for the EOL life-cycle inventory. This section summarizes the salient points from that memorandum needed to understand the EOL methodology and results. For the EOL analysis, a monitor is assumed to have reached EOL status when:

- it has served its useful life;
- is no longer functional; and/or
- is rendered unusable due to technological obsolescence.

Each of these situations is addressed by either the manufactured or effective lives (defined in Section 2.4).

2.5.1.1 EOL disposition options

The major EOL dispositions considered in this analysis are as follows:

- recycling - including disassembly and materials recovery;
- landfilling - including hazardous (Subtitle C) and non-hazardous (Subtitle D) landfills;
- remanufacturing - including refurbishing or reconditioning (to make usable again); and
- incineration - waste to energy incineration.

See Appendix I for further descriptions of these dispositions. Note that reuse is considered part of the use stage and not included as an EOL disposition.

The functional unit in this analysis is one monitor; therefore, the different EOL dispositions were allocated as a probability of one monitor going to a certain EOL disposition. Data were somewhat scarce on the percent of monitors going to each disposition, especially for the LCD monitors. After literature research and consultation with the project's Technical Work Group, as well as various other industry experts, project partners chose best estimates of disposition distributions. Table 2-21 presents the assumptions used for the EOL life-cycle stage dispositions for the CRT and LCD, respectively. An explanation of the assumptions and the sources of the data are presented in Appendix I.

The values in Table 2-21 have been used in the baseline scenarios for the CRT and LCD LCIs. To address the uncertainty in the LCD estimates, a sensitivity analysis was conducted (which is discussed in Section 2.7.3).

Table 2-21. Distribution of EOL disposition assumptions for the CRT and LCD

Disposition	CRT	LCD
Incineration	15%	15%
Recycling	11%	15%
Remanufacturing	3%	15%
Hazardous waste landfill	46%	5%
Solid waste landfill	25%	50%

Sources: NSC, 1999; EPA, 1998; Vorhees, 2000; CIA, 1997; EIA, 1999b

2.5.1.2 Data collection

Inventory data were needed for each of the EOL dispositions to be included in the life-cycle profiles. Primary data were collected for CRT recycling from three companies. Hazardous/solid waste landfilling and incineration were developed from secondary data obtained from *Ecobilan*. In attempts made to obtain remanufacturing data, it was found that remanufacturing processes span a wide range of activities, from as little as replacing button tops to as extensive as testing and replacing PWBs or transformers. Given the broad range of possibilities, no single set of operations could be identified to adequately represent remanufacturing activities that could be incorporated in our model. Remanufacturing data were, therefore, excluded from the assessment.

Recycling

Companies willing to provide CRT recycling data were given EOL questionnaires, which are similar to the manufacturing questionnaires, but modified as appropriate for the EOL life-cycle stage (see Appendix I). The questionnaires were used as a guide for collecting inventory data. The companies agreed to provide inventory data through personal meetings and telephone conversations rather than completing the detailed questionnaire. As a result, the most critical data were identified by the research team to prioritize data needs, and all the details in the questionnaire may not have been provided.

The three companies contacted were: (1) DMC Recycling; (2) A & B Recycling; and (3) The Oak Ridge National Recycle Center (TORNRC). DMC shreds the complete monitor up and separates the recovered materials into three major material streams: ferrous, silica-based, and copper-based. The ferrous metals are sent to steel mills for recycling, while the other streams are sent to lead and copper smelters, respectively. A & B Recycling performs a partial disassembly of the casing and other materials outside the CRT. These materials (namely, HIPS, steel, aluminum, and copper wiring) are sent for recycling, while the CRT itself is shipped to Envirocycle (a CRT recycler in Pennsylvania), where the glass is recovered and sent for recycling back into CRT glass, and the other materials are also recovered for recycling. TORNRC conducts complete monitor disassembly (which includes the CRT recycling process similar to the one performed at Envirocycle), and recovers the individual materials for subsequent recycling.

None of the recycling companies contacted have yet encountered end-of-life LCDs in any appreciable quantities that would justify the development of a separate recycling process for them. Whatever sporadic quantities of LCDs that they do receive (mainly notebook computer displays) are either sent for refurbishing/resale or are processed along with other electronic equipment, by recovering different materials from them, such as metals, glass, plastics, etc. In the absence of actual data for LCD recycling, the shredding-and-materials-recovery process followed by DMC Recycling for CRTs was assumed to be suitable for recovering materials from LCDs as well, and was therefore used to model LCD recycling.

Landfilling and Incineration

Generic secondary data were used for the incineration and landfilling processes because when monitors are disposed of, they are combined with multiple waste streams, and data for monitors alone are not readily available. Although data specific to landfilling and incineration operations for monitors alone were not available, DEAM inventories from *Ecobilan* were available for landfilling and incinerating the following major monitor materials (by weight): steel, glass, plastic, and aluminum. These inventories were combined, based on the approximate proportion of each material in a CRT and an LCD, to create individual processes for landfilling and for incineration (for each monitor type). The proportions of these materials in a CRT and an LCD, presented in Table 2-22, are estimates of the final assembled monitor based on the manufacturing inventory data. Note that these proportions are slightly different from the proportion of total inputs per functional unit presented in Section 2.1.2, Tables 2-2 and 2-3 because materials efficiency during production is not accounted for here (in Table 2-22). The majority of the assembled monitors by weight is accounted for in the overall incineration and landfilling processes, as seen in the totals in Table 2-22.

It should be noted that some of the DEAM inventories associated with incineration or landfilling are for generic materials (i.e., glass, plastic), and may not accurately represent the makeup of the material used in the monitors. For example, the glass is not leaded glass, and the plastics may not represent the exact breakdown of plastics in the monitors being modeled in this study (see Section 2.5.3, Limitations and Uncertainties for further discussion).

Table 2-22. Percent contribution of major materials in the final product

Material	CRT	LCD
Glass	43% (9.48 kg)	9% (0.585 kg)
Steel	30% (6.61 kg)	47% (3.055 kg)
Plastic	17% (3.75 kg)	40% (2.60 kg)
Aluminum	2% (0.441 kg)	1% (0.065 kg)
Total	**92% (22.043 kg)**	**97% (6.5 kg)**

2.5.1.3 Assumptions

The assumptions used in the EOL life-cycle stage include the percentage breakdown of each EOL disposition option (see Table 2-21), the breakdown of materials for the incineration and landfilling inventories (Table 2-22), as well as those listed in Section 2.2 of Appendix I.

2.5.2 Data Sources and Data Quality

Primary CRT recycling data collected were collected from three companies: A & B Recycling, DMC Recycling, and TORNRC. Efforts were made to collect all data in the questionnaires; however, priority was given to obtaining the inventory data. The companies, preferring to provide data over the phone or during personal meetings, were able to provide the inventory data required for the analyses in this study.

Specific DQIs, such as those reported for the manufacturing data (see Section 2.3.2, Tables 2-14 and 2-15), were not obtained. The data from these companies represent facility operations ranging from October 1999 to February 2000. Also, while the data obtained are from three recycling facilities that may have different operations, the averaged inventory data are intended to be representative of various recycling activities in the industry.

Data for the EOL life-cycle stage are a combination of primary data, for which we do not have specific DQI, and secondary data, with limited data quality information. The overall data quality for this life-cycle stage may therefore be limited, and in relative terms, is lower quality than the manufacturing stage data.

Sources of data for EOL distribution assumptions include the National Safety Council (NSC, 1999), EPA (1998), CIA (1997), EIA (1999b) and Vorhees (2000). These are discussed in Appendix I.

2.5.3 Limitations and Uncertainties

Assumptions of the disposition percentages for CRTs and LCDs may not be truly representative of actual dispositions. Recycling technologies are not yet standardized for the sorting, separation, and processing of different types of CRT glass, metals, and plastics. The methods currently employed by a few large-volume recyclers who have been in the CRT recycling business for some years were used in this study and represent "state-of-the-art" in the CRT recycling industry. The LCD recycling process used was based on a CRT recycling process employed by one of the recycling companies contacted, as it was considered general enough to be applicable to LCDs. In the future, when greater numbers of LCDs begin to arrive at recycling facilities, more standardized processes for handling LCDs specifically might be developed.

Limitations for the incineration and landfilling inventories are that incineration and landfilling of the materials were for generic materials and not specific to actually incinerating or landfilling a CRT or LCD monitor. For the CRT, the glass incineration portion of the monitor is for generic, non-leaded glass. The plastics are also generic plastics (mainly those used for packaging that ultimately end up in municipal solid waste, such as HDPE, LDPE, and PET) and may not account for the flame retardants that might be in the plastics, for example. Also, only a few of the major materials by weight are included in the modeled CRT and LCD that are incinerated (listed in Table 2-22).

2.6 TRANSPORTATION

2.6.1 Methodology

Transportation of materials, products, and wastes throughout a product's life-cycle has environmental impacts and should be included in a comprehensive LCA. However, complete transportation data for all life-cycle stages is often difficult to obtain. Only six of the 16 upstream data sets used for this study explicitly stated that transportation was included. An additional six upstream processes are assumed to have considered transportation (Table 2-9). In the manufacturing stage, transportation data were collected in the questionnaires that were distributed to manufacturers. Some transportation data were provided by manufacturers on materials received by their facility and products and wastes shipped from their facility. Data were not obtained on transportation during the use stage because distributing questionnaires and collecting primary data for the use stage were not within the boundaries and scope of the LCA. Consequently, individual consumer transport to pick up purchased monitors and to send to a secondary user or to a recycling/disposal facility were not accounted for. Similarly, EOL data, either from CRT recyclers, or secondary data for incineration and recycling did not include transportation data. Therefore, the transportation data collected in this study may only represent a small portion of the overall transport in the life of a monitor.

The manufacturing data collection questionnaires (Appendix F) provided space for companies to identify transportation information for each material input, product output, or waste output. The questionnaire asked for the distance traveled, mode of transport (i.e., vehicle type), number of trips per year, and percent capacity of the vehicle containing a particular material of interest. Given this information, the project researchers calculated the total distance traveled for a transportation mode per functional unit.

In order to determine the environmental effects of transport, the total distance traveled must be linked to an inventory associated with a transport mode on a per-distance-traveled basis. *Ecobilan's* DEAM data provided inventories for several vehicles either on a per-distance-traveled basis or a per mass-load, per-distance-traveled basis. Given the maximum load of the vehicle, the latter figures can also be used with the transportation data collected in the manufacturing questionnaires to estimate the total distance traveled per mode per functional unit.

2.6.2 Questionnaire Results

In many cases, companies completing the questionnaires provided partial transportation data. For the CRT processes, manufacturers supplied adequate transportation data for 66% of the materials that are expected to have transportation data. For the LCD processes, 73% of the materials had adequate transportation data to determine the total distance traveled per mode per functional unit. Of the transportation data that were provided, Table 2-23 lists the distribution of transport modes for the CRT and LCD manufacturers. To complete the LCI, transport data from the questionnaires would have to be linked to vehicle inventories, which were available through the DEAM data. However, the vehicle inventories were not linked to the questionnaire data because the questionnaire asked for percent capacity, but did not couple that with the load capacity of the vehicle. As a result, the data were inconsistent and could not accurately be used in the overall product LCI.

Table 2-23. Distribution of transport modes and total distances per mode

Transport mode	CRT		LCD	
	Distribution of modes	Approx. normalized [a] distance traveled per functional unit	Distribution of modes	Approx. normalized* distance traveled per functional unit
Large diesel truck	61%	3 km	58%	3 km
Small diesel or gas truck	21%	<1 km	35%	<1 km
Ocean	16%	37 km	3%	<1 km
Rail	2%	<1 km	2%	<1 km
Air	0%	0	2%	52 km
Total	100%	40 km	100%	56 km

[a] Normalized by the percent capacity of a vehicle carrying the material of interest.
Note: 1 km = 0.6215 miles.

In order to use the vehicle inventory data, it would have to be assumed that the load capacity assumed by manufacturers when providing the percent capacity was consistent with that in the DEAM vehicle inventory data. However, conducting a review of the DEAM data versus the questionnaire data showed that this was not consistent. The greatest difference (based on relatively crude averages of all the transport data provided) appeared to be for the ocean transport, where the discrepancy was on the order of tens of millions of times different. The other modes appeared to be between 22,000 to 660,000 times. These huge discrepancies puts the linked transportation data into question, making it unreliable for use in this study. When the transportation impacts were run in the analysis, and these factors applied, the transportation impacts appeared to be small compared to the other life-cycle stages, but no real reliable information can be gleaned from these data. Further work is needed in this area to understand the true transportation impacts. For this report, the transportation-related inventories are not included.

Transportation data that can be used from the questionnaires include the modes of transport used and the total distances traveled per functional unit (by mode). These are presented in Table 2-23. The "normalized" distance is the total distance traveled for each material multiplied by the percent capacity of the vehicle that was carrying the particular material of interest. This was done to allocate a portion of the vehicle (and thus a portion of the associated inputs and outputs for transport in a particular vehicle) to the transport of the material of interest. It should be noted that these percent capacities were assumptions made by the manufacturers who completed the questionnaires and the percent capacity assumptions could have been inconsistently interpreted. Not only are the distances modified to represent only the product of interest, they are scaled to represent one functional unit (i.e., the material, product, or waste associated with one monitor). Thus, the total normalized distance for the CRT is 40 kilometers (km) per functional unit and 56 km per functional unit for the LCD. These numbers are normalized with the intention of linking them to the individual vehicle inventories, but as stated above, this has not been done due to data inconsistencies.

The most frequently used mode of transport for both the CRT and LCD is the large diesel truck, followed by the small gas or diesel truck. However, the largest normalized distance traveled for the CRT is via ocean transport and for the LCD is via air transport. Worth noting again is that these distances were calculated by normalizing the capacity of the vehicle, as assumed by the manufacturer. Although the transport data represent transport of several materials, products, and wastes into and out of manufacturing facilities, the majority of the distances traveled are from the transport of the final assembled monitors. Of all the reported transportation for the manufacturing stage, the distance traveled of a final assembled CRT monitor via the ocean represents 80% of the total distance traveled. For the LCD, 90% of all reported kilometers traveled are for transport of the final assembled LCD monitor via airplane. Transport of the final assembled CRT monitor for all transport modes is 86% of all kilometers traveled per functional unit. Similarly, for the final assembled LCD monitor, approximately 92% of all manufacturing transportation reported is for the final assembled monitor.

2.6.3 Data Sources and Data Quality

Primary data were derived from manufacturing questionnaires and inventory data for transport vehicles were available through DEAM data. However, inconsistencies between the data made it impossible to accurately apply the DEAM inventories to the questionnaire data. Therefore, the data quality is very low and complete transportation inventory data are excluded from the analysis results.

2.6.4 Limitations and Uncertainties

Inconsistencies between data collected in questionnaires and DEAM data made it impossible to use the transportation inventory data as part of the overall life-cycle. From rough estimates based on data received, it is possible that the transportation impacts are not driving overall life-cycle impacts, however, this would need to be investigated further to confirm such a conclusion.

2.7 SUMMARY OF LIFE-CYCLE INVENTORY RESULTS

2.7.1 Baseline LCI

This section presents the baseline inventory data for the life-cycles of the CRT and LCD monitors. The baseline scenario meets the following conditions:

- uses the effective life use stage scenario;
- uses the average value of all the energy inputs from the primary data for glass manufacturing;
- assumes LCD glass manufacturing processes use the same amounts of energy as CRT glass manufacturing per kilogram of glass produced;
- excludes two outliers from the average of the energy inputs in the LCD panel/module manufacturing inventory;
- excludes transportation in the manufacturing stage, but includes any transportation embedded in upstream data sets; and,
- includes the manufacturing process of materials used as fuels (e.g., natural gas, fuel oils) in the life-cycle stage in which they are consumed instead of in the materials processing stage. In cases where materials normally considered to be fuels are used as ancillary materials their manufacturing processes are included with other upstream processes.

Inventory data presented here are used to calculate impacts in the impact assessment (Chapter 3), which translates inventory items into impacts. Note that only limited conclusions can be made based on the inventory alone.

Table 2-24 presents the total quantity of inputs and outputs for the entire life-cycles of the CRT and LCD based on input and output types. Definitions of the input and output types were presented in Table 2-1 in Section 2.1.1. Graphs depicting selected input and output types, derived from the values in Table 2-24, are in Figures 2-5, 2-6, and 2-7. Complete inventory tables for each input and output type by life-cycle stage for the CRT and LCD are provided in Appendix J. The inventories presented in Appendix J list each individual input or output alphabetically for a particular input or output type. The individual inputs or outputs may be the sum of that material for several processes.

The total inventory results for life-cycle inputs reveal that more primary materials,[3] water, fuels, electricity, and total energy (i.e., fuel energy plus electricity) are used throughout the CRT life-cycle while more ancillary materials are used throughout the LCD life-cycle. For the life-cycle outputs, the CRT releases more air emissions; water pollutants; hazardous, solid, and radioactive waste; and radioactivity than the LCD. The LCD releases more total wastewater than the CRT. The data that comprise the inventory totals presented in Table 2-24 are listed in Appendix J and broken down by life-cycle stage. Further details on the inventory are provided for each monitor type below.

[3] Note that the total mass of primary materials includes the inputs to each process, which may duplicate materials used in processes subsequent to other processes. For example, the primary materials used in steel production are added to the steel used as a primary material for monitor assembly.

Table 2-24. Total life-cycle inventory summary - baseline analysis

Inputs	CRT	LCD	Units
Primary materials	**6.53e+02**	3.63e+02	kg/functional unit
Ancillary materials	1.98e+01	**2.08e+02**	kg/functional unit
Water	**1.31e+04**	2.82e+03	kg (or L)/functional unit
Fuels	**4.33e+02**	3.86e+01	kg/functional unit
Electricity	**2.49e+03**	1.20e+03	MJ*/functional unit
Total energy	**2.08e+04**	2.84e+03	MJ*/functional unit
Outputs			
Air pollutants	**6.64e+02**	3.46e+02	kg/functional unit
Wastewater	1.52E+03	**3.13e+03**	kg (or L)/functional unit
Water pollutants	**2.09E+01**	1.68e+00	kg/functional unit
Hazardous waste	**9.46e+00**	6.29e+00	kg/functional unit
Solid waste	**1.72e+02**	5.23e+01	kg/functional unit
Radioactive waste	**2.90e-03**	1.48e-03	kg/functional unit
Radioactivity	**8.98e+07**	4.01e+07	Bq/functional unit

* 3.6 MJ = 1 kWh
Note: Bold indicates the larger value when comparing the CRT and LCD.

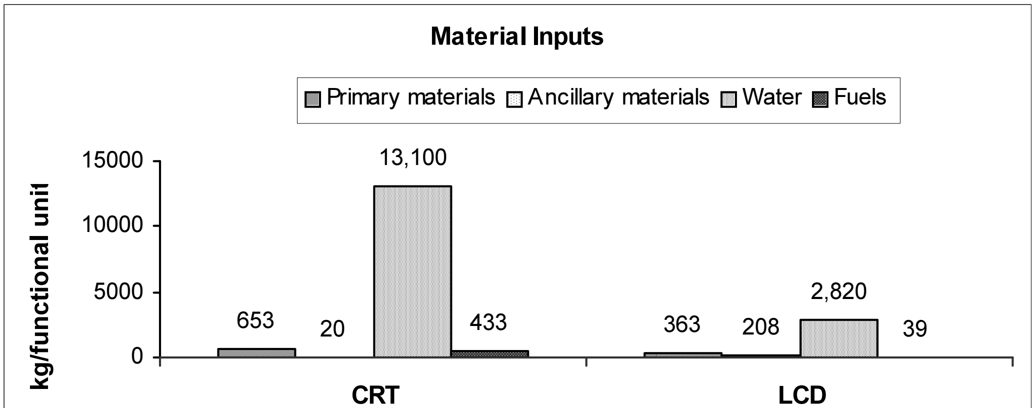

Figure 2-5. Mass-based life-cycle inputs

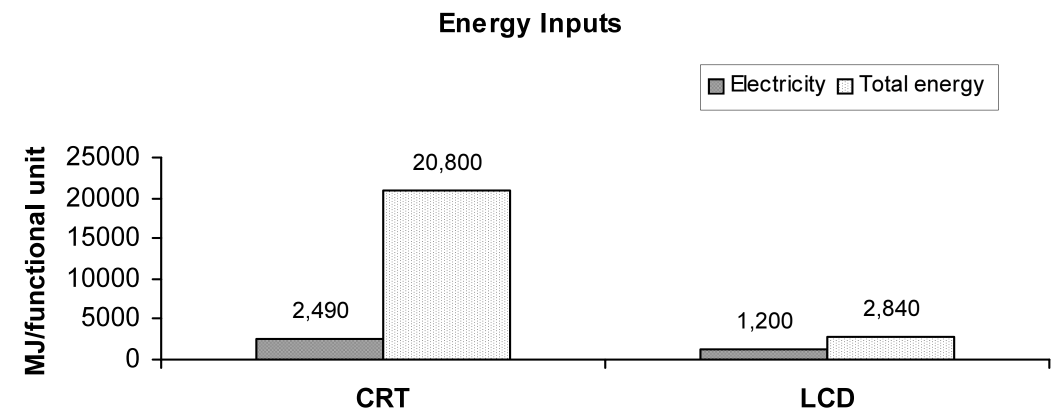

Figure 2-6. Energy-based life-cycle inputs

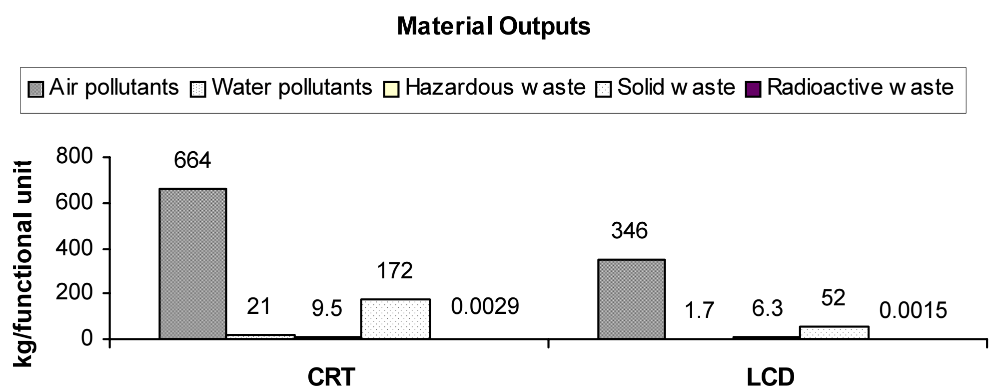

Figure 2-7. Mass-based life-cycle outputs (excluding total wastewater)

2.7.1.1 CRT inventory results

The total CRT inventory presented in Table 2-24 and Figures 2-5, 2-6, and 2-7 show the inventory from all life-cycle stages combined. The totals by life-cycle stage are presented in Table 2-25, Figures 2-8, 2-9, and 2-10.

Table 2-25. CRT inventory by life-cycle stage

Inventory type	Upstream	Mfg	Use	EOL	Total	Units [a]
Inputs						
Primary materials	1.58e+01	4.21e+02	2.19e+02	-3.32e+00	6.53e+02	kg
Ancillary materials	2.11e+00	3.54e+00	3.47e+00	1.07e+01	1.98e+01	kg
Water	5.54e+02	1.14e+04	1.14e+03	-2.73e+01	1.31e+04	kg (or L)
Fuels	??	??	??	??	0.00e+00	kg
Electricity	7.32e+01	1.29e+02	2.29e+03	2.29e-01	2.49e+03	MJ
Total energy	3.66e+02	1.83e+04	2.29e+03	-1.28e+02	2.08e+04	MJ
Outputs						
Air pollutants	3.00e+01	1.83e+02	4.49e+02	2.47e+00	6.64e+02	kg
Wastewater	1.70e+01	1.51e+03	0	-3.65e+00	1.52e+03	kg (or L)
Water pollutants	8.12e-01	2.01e+01	7.02e-02	-6.18e-02	2.09e+01	kg
Hazardous waste	??	??	0	??	9.46e+00	kg
Solid waste	9.55e+00	8.12e+01	8.33e+01	-1.66e+00	1.72e+02	kg
Radioactive waste	4.39e-04	1.80e-04	2.28e-03	2.29e-07	2.90e-03	kg
Radioactivity	3.80e+07	3.78e+06	4.80e+07	4.80e+03	8.98e+07	Bq

[a] Per functional unit (i.e., one CRT monitor over its effective life).

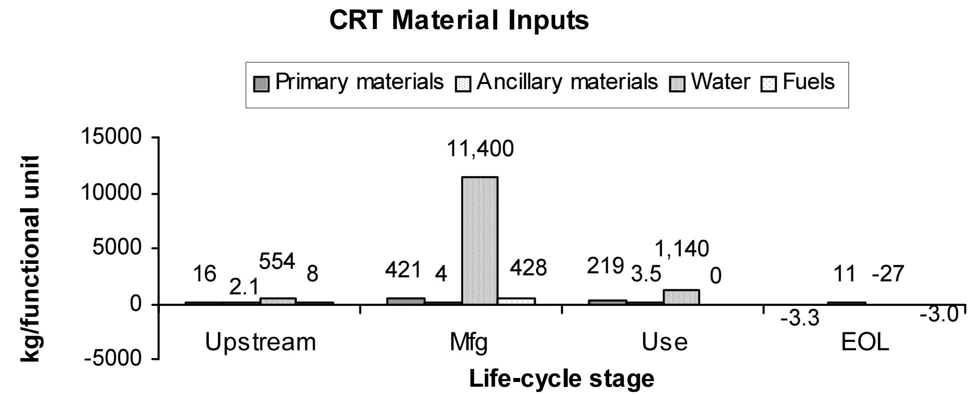

Figure 2-8. CRT Mass-based material inputs by life-cycle stage

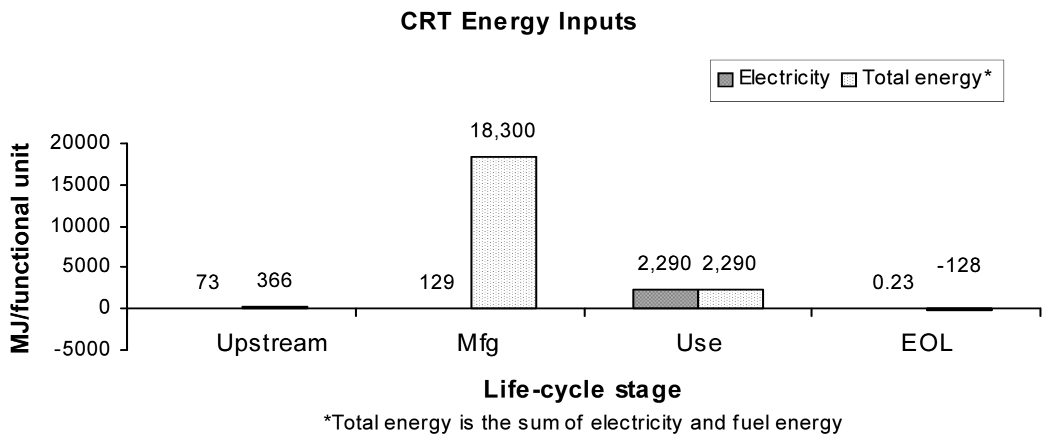

Figure 2-9. CRT Energy-based inputs by life-cycle stage

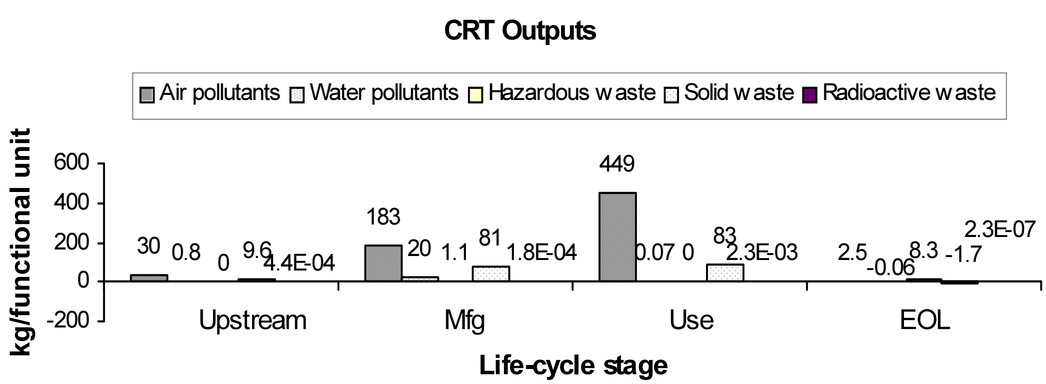

Figure 2-10. CRT mass-based outputs by life-cycle stage

Considering inputs, Figure 2-8 shows that of the inputs measured in mass, the water inputs in the manufacturing life-cycle stage constitute the majority of the inputs by mass for the entire life cycle. Water inputs from the LPG production process constitute almost 80% of the water inputs for all life-cycle stages. In this inventory, the LPG is used in large quantities as a fuel in CRT glass manufacturing. When considering which life-cycle stage contributes most to an inventory category, the manufacturing stage has the largest inventory by mass for primary materials, ancillary materials, water inputs, and fuel inputs. This is also due to the production of LPG as needed for CRT glass production. Fuel inputs are dominated by the manufacturing stage and electricity inputs are dominated by the use stage. The total energy (which is calculated by converting the mass of the fuel into units of energy and combining the fuel energy with the electrical energy[4]) is dominated by the manufacturing life-cycle stage, again mostly due to the large LPG fuel energy used in CRT glass production (Figure 2-9).

Outputs measured in mass include air emissions, wastewater, water pollutants and hazardous, solid, and radioactive waste. Wastewater, by mass (or volume), constitutes the greatest output; however, wastewater alone will not be used to calculate water-related impacts. Water pollutants are also used to calculate water-related impacts. Of the remaining outputs measured in mass (i.e., air emissions, and hazardous, solid and radioactive waste), which are shown on Figure 2-10, air emissions are the greatest contributor to outputs in mass. Note that radioactivity is measured in Bequerels (Bq) and cannot be compared on the same scale.

Considering each inventory type and their contributions by life-cycle stage, the mass of wastewater and water pollutants are greatest in the manufacturing life-cycle stage (again due to LPG consumption). The outputs of air emissions, hazardous waste, solid waste, radioactive waste, and radioactivity all have the greatest contribution from the use stage.

For the outputs, all the totals represented in Table 2-25 include outputs to all dispositions. For example, water outputs sent offsite to treatment as well as those directly discharged to surface waters are all included. Similarly, hazardous, solid and radioactive waste outputs may be landfilled, treated or recycled. The inventory shows these as totals; however, when impacts are calculated, the dispositions dictate which inventory items will be used to calculate impacts (Chapter 3).

The tables and figures discussed above show the total inventories for particular input or output types by life-cycle stage. Tables in Appendix J list each material that contributes to those totals. Figures 2-11 through 2-23 show the total contribution by life-cycle stage, based on the entire input/output type-specific tables in Appendix J. Summary tables for the CRT (Tables 2-26 through 2-34), developed from the Tables in Appendix J, show the top contributing inventory items to each input or output type. Note that Table 2-28 includes input/output types that are classified together as utilities: water, fuel, electricity and total energy.

[4] Conversions and calculations of energy impacts are described in the LCIA methodology discussion in Chapter 3.

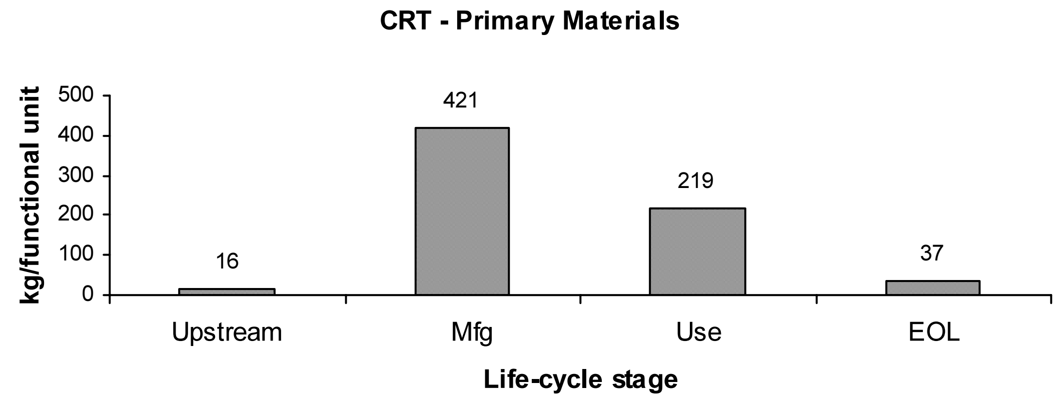

Figure 2-11. CRT primary material inputs by life-cycle stage

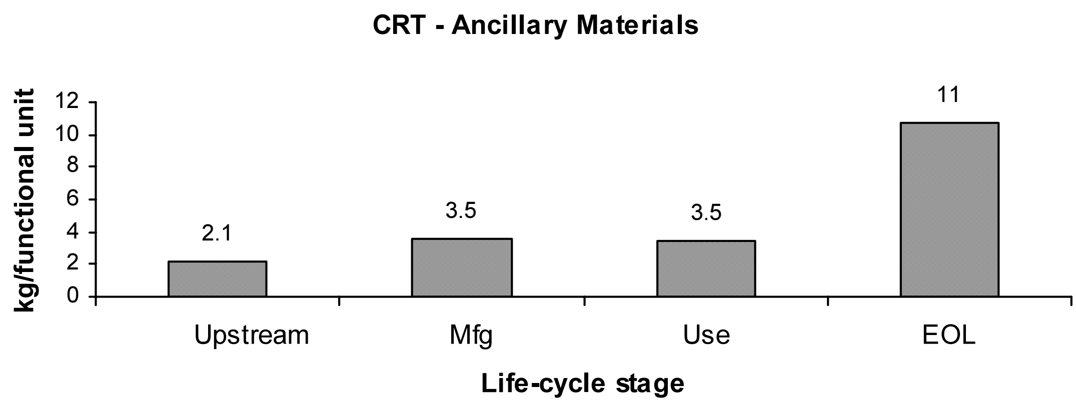

Figure 2-12. CRT ancillary material inputs by life-cycle stage

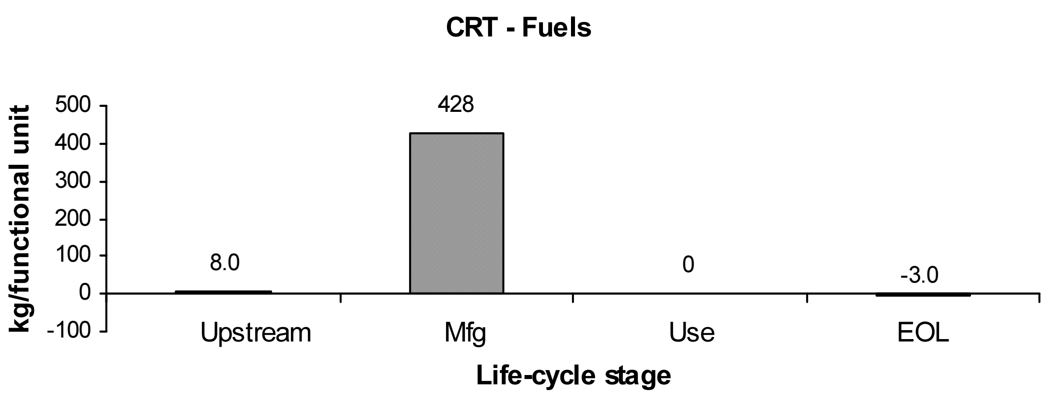

Figure 2-13. CRT fuel inputs by life-cycle stage

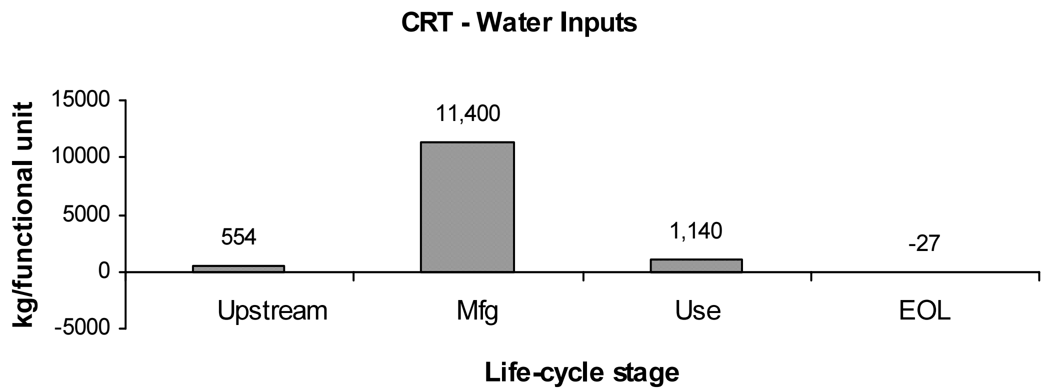

Figure 2-14. CRT water inputs by life-cycle stage

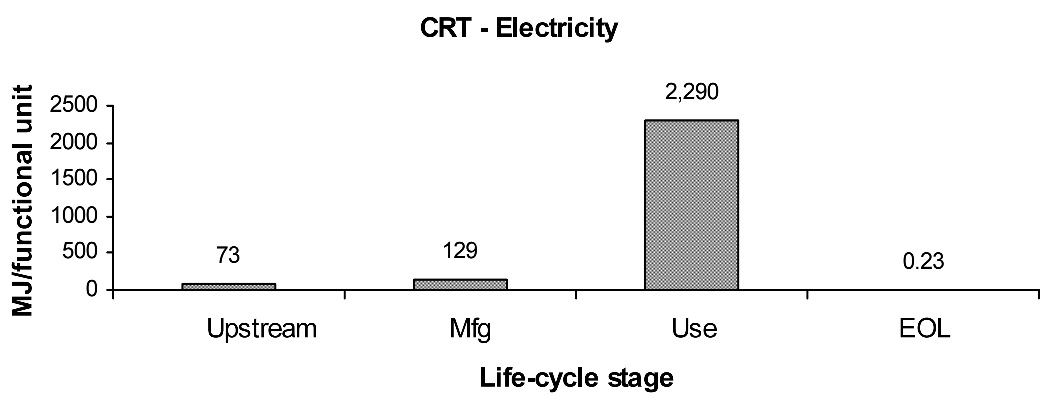

Figure 2-15. CRT electricity inputs by life-cycle stage

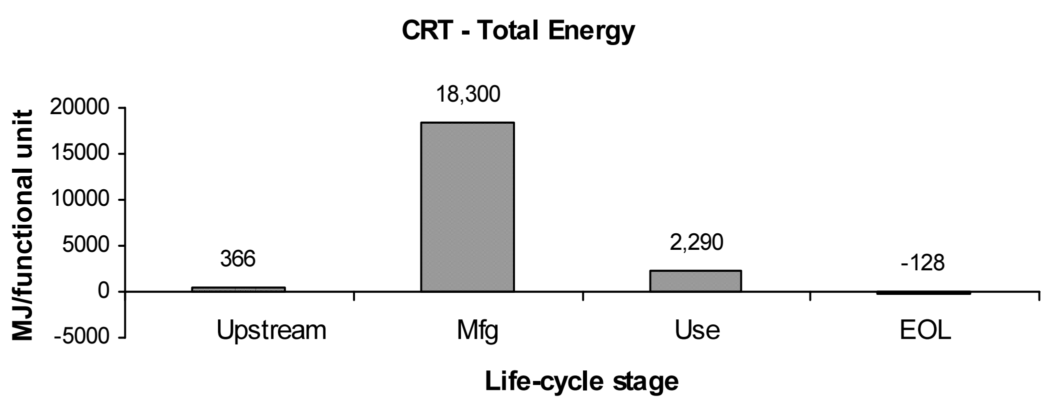

Figure 2-16. CRT energy inputs by life-cycle stage

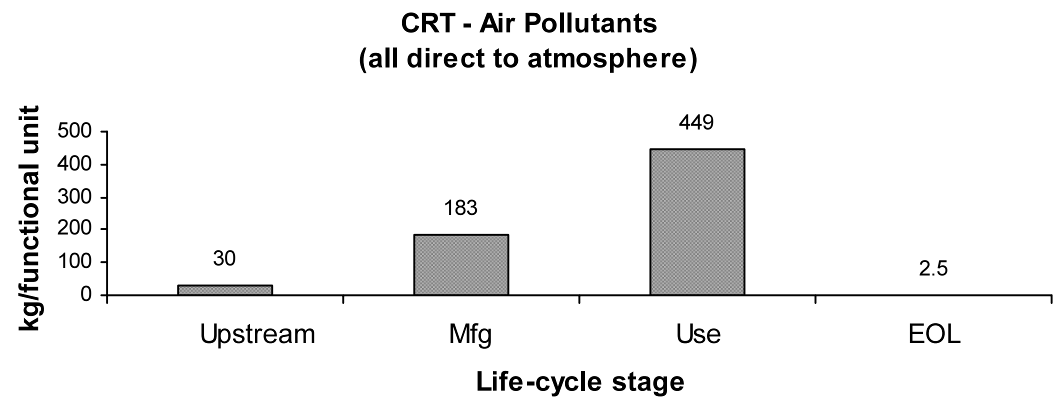

Figure 2-17. CRT air outputs by life-cycle stage

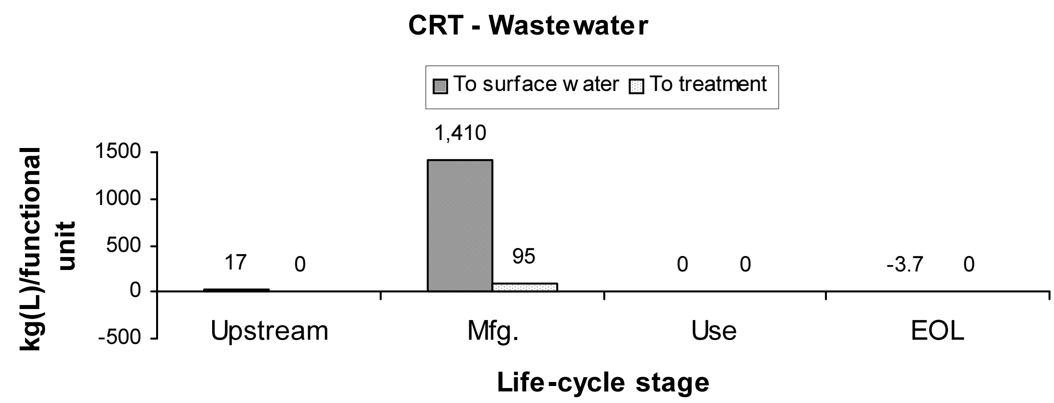

Figure 2-18. CRT wastewater outputs by life-cycle stage

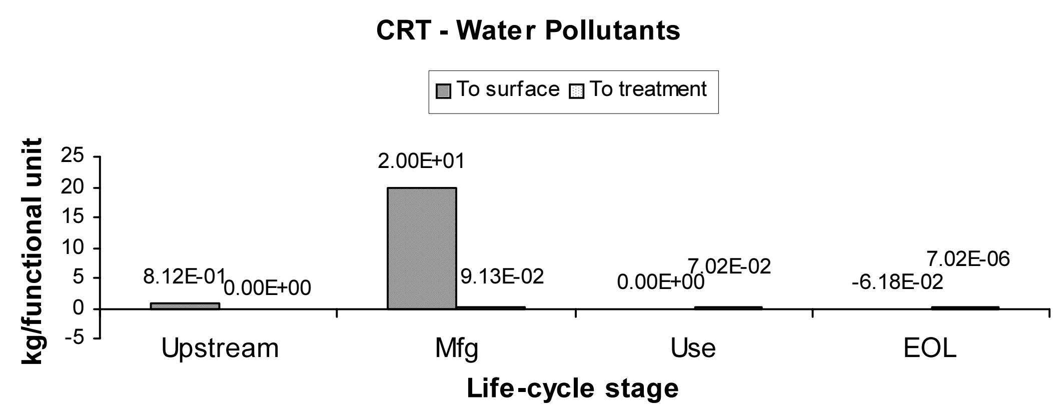

Figure 2-19. CRT waste pollutant outputs by life-cycle stage

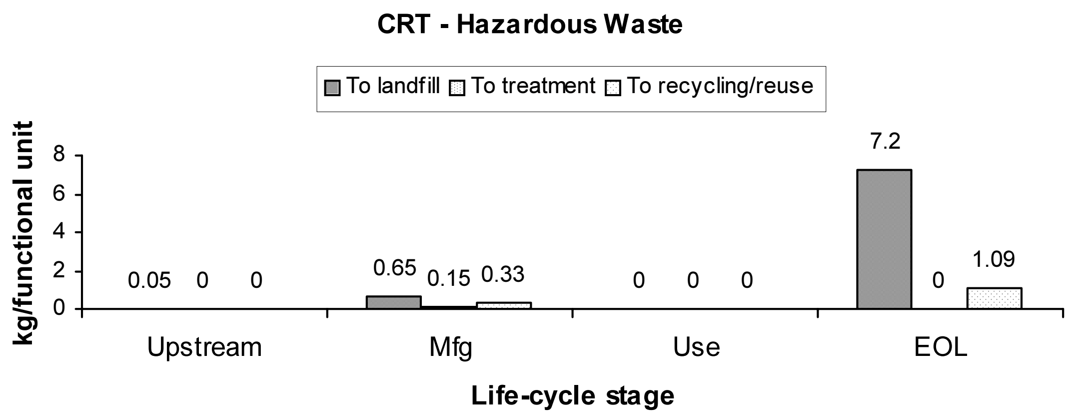

Figure 2-20. CRT hazardous waste outputs by life-cycle stage

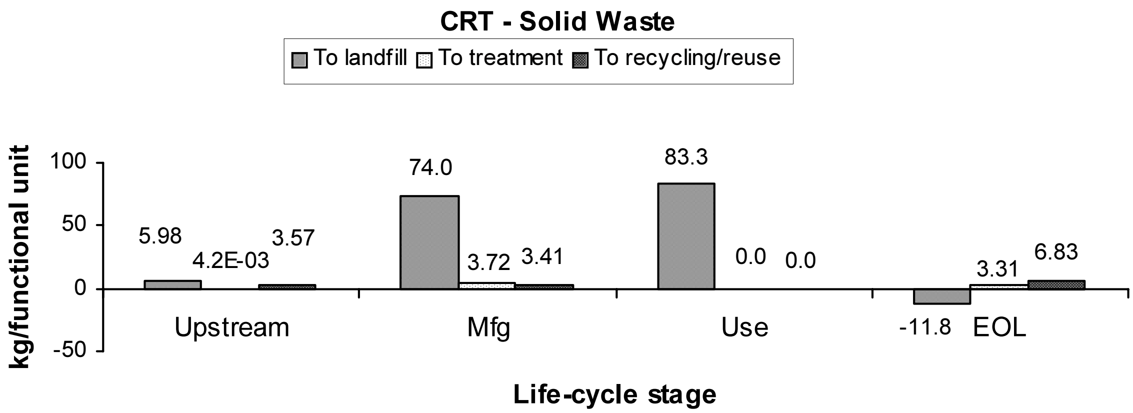

Figure 2-21. CRT solid waste outputs by life-cycle stage

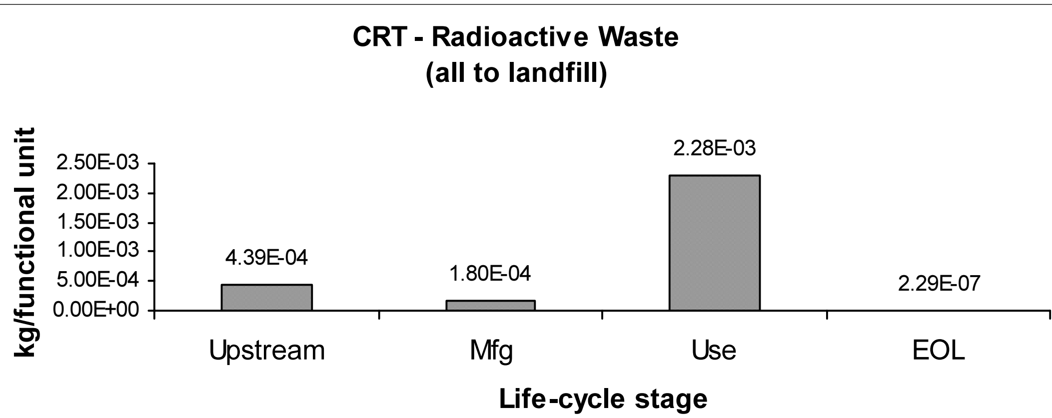

Figure 2-22. CRT radioactive waste outputs by life-cycle stage

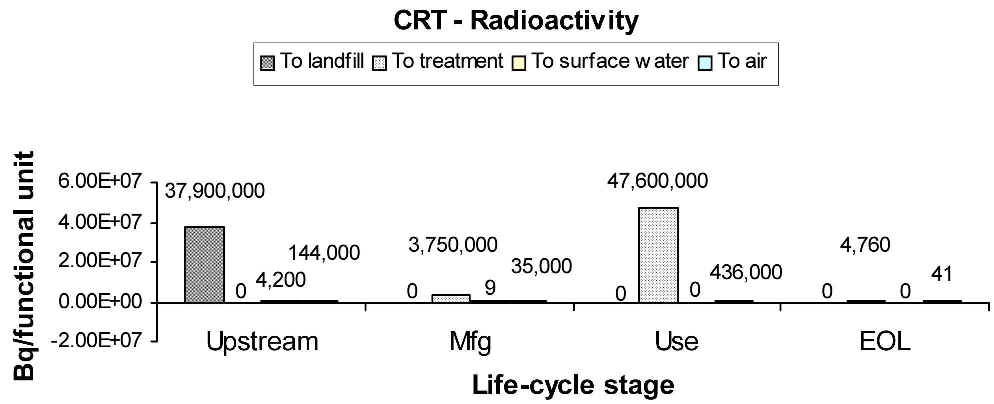

Figure 2-23. CRT radioactivity outputs by life-cycle stage

CRT Primary Inputs

Beginning with the primary data inputs, Figure 2-11 shows that most primary materials are from the manufacturing and use life-cycle stages. To better understand what some of the top contributing materials are to those life-cycle stage totals, Table 2-26 shows the top 99% of the materials contributing to the total CRT primary input inventory. As shown in Table 2-26, the largest material contributor is petroleum, which is about 54% of all the primary CRT inputs. The petroleum is mostly (>98%) from the LPG production process, which relates back to the LPG needed as a fuel in glass production. The other major contributor to primary material inputs is coal (~27%) which is used to produce electricity consumed in the use stage. More detail on the processes that contribute greatest within the manufacturing stage will be presented below after brief discussions of the life-cycle stage breakdowns for each inventory type. For the complete list of primary materials in the CRT inventory, the total mass, and the mass contribution of each life-cycle stage, see Appendix J-1, Table J-1.

CRT Ancillary Inputs

Observing Figure 2-12, the mass of ancillary CRT inputs in the EOL life-cycle stage was greatest (11 kg/functional unit). The upstream stages had the lowest mass of ancillary inputs compared to the other life-cycle stages. To better understand the materials contributing to those totals, Table 2-27 shows that clay is the greatest contributor by mass at 41% of the total CRT ancillary inputs. Clay is used predominately during EOL incineration and landfilling. See Table J-2 in Appendix J for the complete list of ancillary materials in the CRT inventory.

Table 2-26. Top 99% of CRT primary materials inputs (kg/functional unit)

Material	Upstream	Mfg	Use	EOL	Total	% of total
Petroleum (in ground)	1.32E+00	3.72E+02	3.80E+00	-1.52E+00	3.75E+02	54.17%
Coal, average (in ground)	3.57E+00	5.15E+00	1.79E+02	1.79E-02	1.88E+02	27.15%
Assembled CRT monitor	0	0	2.20E+01	0	2.20E+01	3.38%
Natural gas	0	1.47E+00	1.40E+01	-8.88E-02	1.54E+01	2.36%
Cathode ray tube (CRT)	0	1.07E+01	0	0	1.07E+01	1.64%
CRT glass, unspecified	0	9.76E+00	0	0	9.76E+00	1.50%
Iron (Fe, ore)	6.90E+00	0	0	0	6.90E+00	1.06%
Steel	2.48E-06	5.16E+00	0	0	5.16E+00	0.79%
Natural gas (in ground)	8.41E-01	3.27E+00	0	-1.64E+00	2.47E+00	0.38%
Sand	0	2.40E+00	0	0	2.40E+00	0.37%
Recycled CRT Glass	0	2.06E+00	0	0	2.06E+00	0.32%
Bauxite (Al2O3, ore)	1.37E+00	0	0	0	1.37E+00	0.21%
Iron scrap	9.46E-01	0	0	0	9.46E-01	0.14%
Polycarbonate resin	0	9.23E-01	0	0	9.23E-01	0.14%
PWB-laminate	0	8.47E-01	0	0	8.47E-01	0.13%
Printed wiring board (PWB)	0	8.47E-01	0	0	8.47E-01	0.13%
Styrene-butadiene copolymers	0	8.27E-01	0	0	8.27E-01	0.13%
PPE	0	7.35E-01	0	0	7.35E-01	0.11%

See Appendix J for complete inventory table.

Table 2-27. Top 99% of CRT ancillary materials inputs (kg/functional unit)

Material	Upstream	Mfg	Use	EOL	Total	% of total
Clay (in ground)	4.49e-03	0	0	8.19e+00	8.19e+00	41.35%
Sand (in ground)	5.85e-02	2.74e-02	0	2.71e+00	2.80e+00	14.13%
Limestone	0	6.91e-02	2.41e+00	2.41e-04	2.48e+00	12.51%
Limestone (CaCO3, in ground)	8.60e-01	1.08e+00	0	-2.39e-01	1.70e+00	8.58%
Lime	0	3.04e-02	1.06e+00	1.06e-04	1.09e+00	5.49%
Sodium chloride (NaCl, in ground or in sea)	7.61e-01	1.26e-02	0	-3.07e-05	7.73e-01	3.90%
Sulfuric acid	0	2.38e-01	0	0	2.38e-01	1.20%
Hydrochloric acid	0	2.36e-01	0	0	2.36e-01	1.19%
Sodium hydroxide	0	1.98e-01	0	0	1.98e-01	1.00%
Pyrite (FeS2, ore)	1.94e-01	0	0	0	1.94e-01	0.98%
Nitric acid	0	1.44e-01	0	0	1.44e-01	0.73%
Ferric chloride	0	1.37e-01	0	0	1.37e-01	0.69%
Calcium Chloride	0	1.27e-01	0	0	1.27e-01	0.64%
Calcium hydroxide	0	9.54e-02	0	0	9.54e-02	0.48%
Hydrofluoric acid	0	8.65e-02	0	0	8.65e-02	0.44%
Hydrogen peroxide	0	8.45e-02	0	0	8.45e-02	0.43%
Ammonium hydroxide	0	7.90e-02	0	0	7.90e-02	0.40%
Pumice	0	7.86e-02	0	0	7.86e-02	0.40%
Ammonium chloride	0	7.76e-02	0	0	7.76e-02	0.39%

Table 2-27. Top 99% of CRT ancillary materials inputs (kg/functional unit)

Material	Upstream	Mfg	Use	EOL	Total	% of total
Alkali cleaning agent	0	7.72e-02	0	0	7.72e-02	0.39%
Iron (Fe, ore)	7.23e-02	0	0	3.41e-03	7.57e-02	0.38%
Potassium peroxymonosulfate	0	7.06e-02	0	0	7.06e-02	0.36%
Sulfuric acid, aluminum salt	0	6.75e-02	0	0	6.75e-02	0.34%
Alkali soda (to neutralize acid waste water)	0	5.45e-02	0	0	5.45e-02	0.28%
Polyethylene glycol	0	5.04e-02	0	0	5.04e-02	0.25%
Bauxite (Al2O3, ore)	1.10e-03	4.47e-02	0	-1.14e-04	4.57e-02	0.23%
Nitrogen	0	4.57e-02	0	0	4.57e-02	0.23%
PWB-solder mask solids	0	4.37e-02	0	0	4.37e-02	0.22%
Potassium hydroxide	0	4.27e-02	0	0	4.27e-02	0.22%
Lubricant (unspecified)	4.11e-02	0	0	0	4.11e-02	0.21%
Chlorine	0	4.03e-02	0	0	4.03e-02	0.20%
Zinc (Zn, ore)	3.79e-02	0	0	0	3.79e-02	0.19%
Aluminum Oxide	0	3.37e-02	0	0	3.37e-02	0.17%
Oil (in ground)	0	0	0	3.35e-02	3.35e-02	0.17%
Sodium Carbonate	0	3.22e-02	0	0	3.22e-02	0.16%
Tin (Sn, ore)	2.43e-02	0	0	0	2.43e-02	0.12%

See Appendix J for complete inventory table.

CRT Utility Inputs

Utility inputs in the CRT life-cycle are presented in the inventory in Table 2-28 and include fuel (kg/functional unit), electricity (MJ/functional unit), and water (kg or L/functional unit) inputs. Figures 2-13, 2-14, and 2-15 show the total fuels, water, and electricity inputs, respectively. The fuel and electricity inputs have also been combined into a total energy input category, shown in Figure 2-16. This is also considered one of the impact categories of the LCIA that will be presented in Chapter 3. Therefore, more details on how it is calculated are available in Chapter 3. Briefly, the mass of the fuels are converted to units of energy and added to the electrical energy quantities (in units of MJ).

Table 2-28. CRT utility inputs

Material	Upstream	Mfg	Use	EOL	Total	% of total
Fuels (kg/functional unit):						
LPG	0	3.51E+02	0	3.03E-03	3.51E+02	81.10%
Natural gas (in ground)	2.76E+00	4.56E+01	0	-2.09E-01	4.82E+01	11.14%
Coal, average (in ground)	2.25E+00	1.36E+01	0	-1.16E-02	1.58E+01	3.66%
Petroleum (in ground)	2.02E+00	9.71E+00	0	-5.77E-02	1.17E+01	2.70%
Fuel oil #6	0	3.68E+00	0	0	3.68E+00	0.85%
Fuel Oil #2	0	1.16E+00	0	0	1.16E+00	0.27%
Natural gas	0	2.44E+00	0	-1.30E+00	1.14E+00	0.26%
Coal, lignite (in ground)	9.73E-01	0	0	0	9.73E-01	0.22%
LNG	0	3.35E-01	0	0	3.35E-01	0.08%
Uranium (U, ore)	1.21E-04	2.29E-04	0	-1.99E-07	3.49E-04	<0.01%
Fuel oil #4	0	1.37E-01	0	-1.38E+00	-1.24E+00	-0.29%
Total fuels	8.00E+00	4.28E+02	0	-2.95E+00	4.33E+02	100.00%
Electricity (MJ/functional unit):						
Electricity	7.32E+01	1.29E+02	2.29E+03	2.29E-01	2.49E+03	
Water (kg or L/functional unit):						
Water	5.54E+02	1.14E+04	1.14E+03	-2.73E+01	1.31E+04	
Total energy (fuels and electricity, MJ/functional unit):						
Energy	3.66E+02	1.83E+04	2.29E+03	-1.28E+02	2.08E+04	

Table 2-28 shows that LPG used in the manufacturing stage dominates the fuel inputs. LPG from the manufacturing stage is equal to about 81% of all the fuel inputs in the CRT life-cycle. More detail into the process-specific contributions within the manufacturing stage will be presented below at the end of this section. Electricity inputs, however, are dominated by the use stage (~92% of all electricity throughout the CRT life-cycle). When fuel energy and electrical energy are combined into a total energy input value, the overall energy from manufacturing greatly exceeds that from the use stage (18,300 MJ/functional unit versus 2,290 MJ/functional unit). This is depicted in Figure 2-16.

The other utility listed in Table 2-28 is water. Nearly 87% of the water inputs in the CRT life-cycle are from the manufacturing processes; and nearly 80% are from LPG production alone. The life-cycle stage contributing the next most is the use stage at 8.7%. This is from the water used to generate electricity used during the use stage. The upstream stages only contribute about 4% to the total water inputs for the CRT life-cycle. Table J-3 in Appendix J provides the complete list of inventory items for the CRT.

CRT Air Outputs

Air emissions from the CRT life cycle are dominated from the use stage as seen in Figure 2-17. This indicates that most air emissions by mass are from the generation of electricity used by consumers of the monitors. Nearly 68% of the total life-cycle air emissions by mass (or 450 kg/functional unit) are from the use stage. Carbon dioxide (CO_2) alone constitutes 445 kg/functional unit (or about 66% of all air emissions by mass in the life-cycle and nearly 99% of the use stage air emissions). Table 2-29 reveals the individual contribution of CO_2 and other inventory items that contribute to the top 99.99% of air emissions. (See Appendix J for complete inventory table.) These are organized from the air emissions that are the largest contributors to those that are the smaller contributors. Table J-4 in Appendix J shows the contribution of every air emission in the inventory, organized alphabetically. The next largest air emissions, by life-cycle stage, are emitted during the manufacturing stage, which contribute about 28% to the total life-cycle air emissions. Almost 85% of that is air emissions from the LPG production process. All the air emissions in the CRT inventory are designated as direct emissions to the ambient environment.[5]

Table 2-29. Top 99.99% of CRT air pollutant emissions (kg/functional unit)

Material	Upstream	Mfg	Use	EOL	Total	% of total
Carbon dioxide	2.92e+01	1.79e+02	4.45e+02	2.59e+00	6.55e+02	98.68%
Sulfur dioxide	3.37e-01	1.26e-01	2.49e+00	8.30e-04	2.96e+00	0.45%
Nitrogen oxides	6.99e-03	6.95e-01	1.18e+00	-1.90e-02	1.86e+00	0.28%
Methane	6.40e-02	9.08e-01	6.45e-01	-4.30e-02	1.57e+00	0.24%
Sulfur oxides	5.71e-03	8.20e-01	0	-2.97e-02	7.96e-01	0.12%
Carbon monoxide	4.18e-02	4.58e-01	8.09e-02	-4.17e-03	5.76e-01	0.09%
PM	1.28e-01	1.31e-01	0	-1.88e-02	2.40e-01	0.04%
Nonmethane hydrocarbons, remaining unspeciated	9.97e-02	1.10e-01	0	-1.91e-03	2.08e-01	0.03%
Hydrocarbons, remaining unspeciated	1.28e-02	1.58e-01	0	-6.12e-04	1.70e-01	0.03%
Hydrochloric acid	2.39e-03	1.12e-02	1.08e-01	-1.04e-03	1.20e-01	0.02%
Other organics	5.60e-04	7.83e-02	0	-3.65e-03	7.52e-02	0.01%
PM-10	0	3.15e-03	5.78e-02	4.78e-06	6.09e-02	0.01%
Nitrogen dioxide	5.76e-02	0	0	1.85e-03	5.95e-02	0.01%

CRT Water Outputs

The volume (or mass) of wastewater released throughout the CRT life-cycle is approximately 1,520 L (kg) per functional unit. Approximately 6% of that is sent to treatment as opposed to direct discharge to surface water (Figure 2-18). The mass of chemical pollutants within the wastewater streams was calculated separately. The total mass of these water pollutants released, presented by life-cycle stage, is shown in Figure 2-19. The manufacturing life-cycle stage contributes the greatest mass of water pollutants with approximately 20 kg per functional unit. This is about 96% of all the water pollutants for the entire life-cycle. The upstream stages have the second greatest mass of water pollutants at nearly 1 kg/functional unit (just under 4%). The use and EOL stages are small contributors, with the EOL being negative due to recovery processes within the EOL stage. Table 2-30 shows the major contributors to the

[5] Note that some companies may not have reported inventory items associated with all output dispositions, as only some dispositions are used for impact calculations. For example, outputs that are treated or recycled and not directly released to the environment are not used in calculating impacts and may not have been reported. This could be applicable to all output inventories.

water pollutant quantities, and reveals that sodium ion, chloride ions and dissolved solids contribute nearly 85% of all the water pollutants to the entire life-cycle. Greater than 95% of the sodium ion outputs are from LPG production and greater than 78% of the chloride ions are from LPG production. As with other input/output types, LPG production used in glass manufacturing has a large impact on the CRT inventory. For the complete inventory, listing water pollutants alphabetically and subtotaled for each life-cycle stage, see Appendix J, Table J-5. Further details on the manufacturing stage will be provided later.

Table 2-30. Top 99.9% of CRT water pollutant outputs (kg/functional unit)

Material	Disposition	Upstream	Mfg.	Use	EOL	Total	% of total
Sodium (+1)	surface water	2.90e-01	7.04e+00	0	-3.08e-02	7.30e+00	34.94%
Chloride ions	surface water	4.29e-01	6.48e+00	0	-2.39e-02	6.88e+00	32.95%
Dissolved solids	surface water	5.30e-03	3.62e+00	0	-8.77e-05	3.62e+00	17.36%
COD	surface water	1.00e-02	1.60e+00	0	-3.94e-03	1.61e+00	7.71%
Suspended solids	surface water	7.72e-03	8.69e-01	0	-2.11e-03	8.74e-01	4.19%
BOD	surface water	3.93e-04	1.95e-01	0	-4.65e-04	1.95e-01	0.93%
Waste oil	surface water	3.65e-03	1.01e-01	0	-3.13e-04	1.04e-01	0.50%
Dissolved solids	treatment	0	8.01e-02	0	0	8.01e-02	0.38%
Sulfate ion (-4)	treatment	0	1.09e-03	6.84e-02	6.84e-06	6.95e-02	0.33%
Sulfate ion (-4)	surface water	3.75e-02	9.61e-04	0	-1.85e-06	3.84e-02	0.18%
Ammonia ions	surface water	3.54e-06	2.76e-02	0	-6.63e-05	2.75e-02	0.13%
Metals, remaining unspeciated	surface water	6.74e-04	9.75e-03	0	-3.42e-05	1.04e-02	0.05%
COD	treatment	0	8.33e-03	0	0	8.33e-03	0.04%
Oil & grease	surface water	0	7.46e-03	0	0	7.46e-03	0.04%
Nitrogen	surface water	4.46e-05	7.18e-03	0	0	7.23e-03	0.03%
Calcium (+2)	surface water	4.96e-03	0	0	0	4.96e-03	0.02%
Carbonate ion	surface water	4.83e-03	0	0	0	4.83e-03	0.02%
Phenol	surface water	6.25e-05	3.63e-03	0	-9.41e-06	3.68e-03	0.02%
Fluoride	surface water	1.89e-05	3.45e-03	0	0	3.47e-03	0.02%
Salts (unspecified)	surface water	1.71e-03	1.62e-03	0	-4.21e-06	3.33e-03	0.02%
Suspended solids	treatment	0	1.29e-03	1.78e-03	1.78e-07	3.07e-03	0.01%
Fluorides (F-)	surface water	9.63e-05	2.97e-03	0	-7.72e-06	3.06e-03	0.01%

CRT Hazardous Waste Outputs

The total mass of hazardous waste generated throughout the life-cycle of the CRT (Figure 2-20) is mostly from the amount of the monitor that is assumed to be placed in a hazardous waste landfill (Table 2-31). This 7.2 kg is based on the proportion of monitors assumed to be hazardous waste as determined in Section 2.5 (EOL) and is approximately 87% of the hazardous waste generated in the EOL stage. Compared to the total mass of hazardous wastes produced throughout the CRT life-cycle, the EOL stage contributes about 88%. The disposition of the waste will be used to determine how impacts are calculated in Chapter 3. Figure 2-20 shows what portion of hazardous wastes are reported as being landfilled, recycled/reused, or treated. The amount of hazardous waste from the upstream and manufacturing stages are negligible, by comparison. Table 2-31 and Table J-6 in Appendix J list the hazardous wastes and where each hazardous waste is disposed.

Table 2-31. Top 99.9% of CRT hazardous waste outputs (kg/functional unit)

Material	Disposition	Upstream	Mfg	Use	EOL	Total	% of total
EOL CRT monitor, landfilled	landfill	0	0	0	7.20E+00	7.20E+00	76.1%
Hazardous waste	landfill	3.85E-04	6.15E-01	0	-1.50E-03	6.14E-01	6.49%
CRT glass, cullet	R/R	0	0	0	4.84E-01	4.84E-01	5.12%
CRT glass, funnel	R/R	0	0	0	2.29E-01	2.29E-01	2.42%
Transformer	R/R	0	0	0	2.28E-01	2.28E-01	2.41%
PWB-waste cupric etchant	R/R	0	2.25E-01	0	0	2.25E-01	2.38%
Printed wiring board (PWB)	R/R	0	0	0	1.46E-01	1.46E-01	1.54%
General hazardous waste	treatment	0	1.24E-01	0	0	1.24E-01	1.31%
PWB-solder dross	R/R	0	6.70E-02	0	0	6.70E-02	0.71%
General hazardous waste	landfill	4.85E-02	0	0	-9.61E-05	4.84E-02	0.51%
PWB-decontaminating debris	treatment	0	1.55E-02	0	0	1.55E-02	0.16%
PWB-route dust	R/R	0	1.20E-02	0	0	1.20E-02	0.13%
PWB-lead contaminated waste oil	treatment	0	1.16E-02	0	0	1.16E-02	0.12%
Chrome liquid waste (D007 waste)	R/R	0	9.80E-03	0	0	9.80E-03	0.10%
Cinders from CRT glass mfg (70% PbO)	landfill	0	8.26E-03	0	0	8.26E-03	0.09%
Unspecified sludge	R/R	0	5.56E-03	0	0	5.56E-03	0.06%
Unspecified sludge	landfill	0	5.22E-03	0	0	5.22E-03	0.06%
CRT glass funnel EP dust (Pb) (D008 waste)	R/R	0	5.01E-03	0	0	5.01E-03	0.05%
Waste acid (mostly 3% HCl solution)	R/R	0	3.93E-03	0	0	3.93E-03	0.04%
Frit	landfill	0	2.99E-03	0	0	2.99E-03	0.03%
Slag and ash	landfill	0	2.47E-03	0	0	2.47E-03	0.03%
Broken CRT glass	landfill	0	1.88E-03	0	0	1.88E-03	0.02%
Hydrofluoric acid	landfill	0	1.78E-03	0	0	1.78E-03	0.02%

R/R: recycling/reuse.
See Appendix J for complete inventory table.

CRT Solid Waste Outputs

Figure 2-21 shows that both the manufacturing and use stages contribute significant amounts of solid waste by mass to the CRT life-cycle. The majority of the solid waste is landfilled. In terms of mass, the greatest contributor to the solid waste outputs for the CRT life-cycle is coal waste that is a result of generating electricity (Table 2-32). Therefore, coal waste is predominately in the use stage, which uses the most electricity, but also in the manufacturing stage, and to a much lesser degree in the EOL stage. Note that the electricity generation processes that support the secondary data used were derived from a different source (i.e., *Ecobilan*) and do not include coal waste as an output; however, the equally large amount of solid waste generated from those processes is listed as "slag and ash" in the upstream and manufacturing inventories. Overall, the top 80% of solid waste generated in the CRT life-cycle is from coal waste, slag and ash, dust/sludge, and fly/bottom ash. Note that different inventories used in this project have varying nomenclature and some of these solid wastes may indeed overlap. Note also that the mass of a CRT monitor that is assumed to be landfilled at the EOL (3.9 kg/functional unit) is only approximately 2% of the total mass of solid waste in the CRT life-cycle. See Appendix J, Table J-7 for the complete CRT solid waste inventory.

Table 2-32. Top 99% of CRT solid waste outputs (kg/functional unit)

Material	Disposition	Upstream	Mfg	Use	EOL	Total	% of total
Coal waste	landfill	0	1.46E+00	5.09E+01	5.09E-03	5.23E+01	30.37%
Slag and ash	landfill	9.65E-02	6.66E+01	0	-1.49E+01	5.18E+01	30.06%
Dust/sludge	landfill	0	5.64E-01	1.97E+01	1.97E-03	2.02E+01	11.75%
Fly/bottom ash	landfill	0	3.65E-01	1.27E+01	1.27E-03	1.31E+01	7.59%
Unspecified solid waste	landfill	4.94E+00	0	0	-7.86E-01	4.15E+00	2.41%
EOL CRT Monitor, landfilled	landfill	0	0	0	3.91E+00	3.91E+00	2.27%
Unspecified solid waste	treatment	0	3.66E+00	0	0	3.66E+00	2.12%
Unspecified solid waste	recycle/reuse	3.07E+00	4.33E-01	0	0	3.50E+00	2.03%
Unspecified waste	landfill	0	3.38E+00	0	-1.49E-02	3.36E+00	1.95%
EOL CRT Monitor, incinerated	treatment	0	0	0	3.31E+00	3.31E+00	1.92%
Iron scrap	recycle/reuse	3.43E-01	0	0	2.50E+00	2.85E+00	1.65%
EOL CRT Monitor, recycled	recycle/reuse	0	0	0	2.42E+00	2.42E+00	1.40%
Broken CRT glass	recycle/reuse	0	1.08E+00	0	0	1.08E+00	0.62%
Mixed industrial (waste)	landfill	4.87E-02	1.00E+00	0	-5.12E-04	1.05E+00	0.61%
Slag and ash	recycle/reuse	0	6.85E-01	0	-3.01E-03	6.82E-01	0.40%
EOL CRT Monitor, remanufactured	recycle/reuse	0	0	0	6.60E-01	6.60E-01	0.38%
Mining waste	landfill	4.48E-01	0	0	-1.90E-06	4.48E-01	0.26%
Mineral waste	landfill	4.42E-01	2.61E-03	0	-6.76E-06	4.44E-01	0.26%
Carbon Steel Scrap	recycle/reuse	0	0	0	4.10E-01	4.10E-01	0.24%
flame retardant high-impact polystyrene (HIPS)	recycle/reuse	0	0	0	4.03E-01	4.03E-01	0.23%
Waste water treatment (WWT) sludge	recycle/reuse	0	3.72E-01	0	0	3.72E-01	0.22%
Ferric chloride	recycle/reuse	0	3.69E-01	0	0	3.69E-01	0.21%
CRT glass, faceplate	recycle/reuse	0	0	0	3.54E-01	3.54E-01	0.21%

CRT Radioactive Waste Outputs

Radioactive waste outputs in the CRT inventory are found only in the electricity generation and cold-rolled steel production process. Therefore, radioactive wastes will be found wherever electricity is used in a process in the CRT life-cycle. Only very small amounts (approximately 0.003 kg/functional unit) of radioactive waste are generated over the entire life-cycle of the CRT (Figure 2-22 and Table 2-33). As expected, the majority of this is linked to the use stage, where most electricity is used in the CRT life-cycle. Low-level radioactive waste (79%) and depleted uranium (20%) are most of the waste, with very small amounts of highly radioactive waste and some unspecified radioactive waste in the inventory. The inventory of radioactive waste outputs is small, and therefore, Table 2-33 lists all material outputs associated with radioactive waste, in descending order of quantity. Table J-8 in Appendix J lists these in alphabetical order.

Table 2-33. CRT radioactive waste outputs (kg/functional unit)

Material	Disposition	Upstream	Mfg	Use	EOL	Total	% of total
Low-level radioactive waste	landfill	4.11E-04	1.38E-04	1.76E-03	1.76E-07	2.31E-03	79.5%
Uranium, depleted	landfill	0	4.15E-05	5.27E-04	5.27E-08	5.69E-04	19.6%
Radioactive waste (unspecified)	landfill	1.88E-05	0	0	0	1.88E-05	0.6%
Highly radioactive waste (Class C)	landfill	8.65E-06	0	0	0	8.65E-06	0.3%
Total radioactive wastes		4.39E-04	1.80E-04	2.28E-03	2.29E-07	2.90E-03	100.0%

CRT Radioactivity Outputs

Radioactivity is also inventoried in this project as isotopes that are released to the environment. Radioactivity is measured in Bequerels and may be released to air, water, or land. The quantity of radioactivity for each life-cycle stage and different dispositions is presented in Figure 2-23. Table 2-34 shows the top 99.9% of the radioactivity outputs.

Table 2-34. Top 99.9% of CRT radioactivity outputs (Bq/functional unit)

Material	Disposition	Upstream	Mfg	Use	EOL	Total	% of total
Molybdenum-99 (isotope)	treatment	0	3.72e+06	4.73e+07	4.73e+03	5.10e+07	56.75%
Plutonium-241 (isotope)	landfill	3.74e+07	0	0	0	3.74e+07	41.67%
Xenon-133 (isotope)	air	2.43e+03	6.28e+03	3.12e+05	3.12e+01	3.21e+05	0.36%
Tritium-3 (isotope)	treatment	0	2.20e+04	2.80e+05	2.80e+01	3.02e+05	0.34%
Plutonium-240 (isotope)	landfill	1.62e+05	0	0	0	1.62e+05	0.18%
Cesium-135 (isotope)	landfill	1.46e+05	0	0	0	1.46e+05	0.16%
Radon-222 (isotope)	air	1.37e+05	0	0	0	1.37e+05	0.15%
Plutonium-239 (isotope)	landfill	1.14e+05	0	0	0	1.14e+05	0.13%
Xenon-133 (isotope)	treatment	0	3.48e+03	4.43e+04	4.43e+00	4.78e+04	0.05%
Tritium-3 (isotope)	air	3.47e+02	2.95e+03	3.74e+04	3.75e+00	4.07e+04	0.05%
Xenon-133M (isotope)	air	0	1.99e+04	2.07e+04	2.07e+00	4.06e+04	0.05%
Krypton-85 (isotope)	air	1.73e+02	2.08e+03	2.65e+04	2.65e+00	2.87e+04	0.03%

See Appendix J for complete inventory table.

Radioactivity outputs are related to the generation of electricity and therefore the greatest quantity of radioactivity is from the use stage, as expected. Table J-9 in Appendix J lists the complete inventory.

CRT Manufacturing Stage

The inventory tables that show the specific materials (i.e., those in Appendix J and Tables 2-26 through 2-34) are the sums of the materials from one or more processes within a life-cycle stage. To burrow down deeper into the data, the manufacturing stage inventory data are broken down by process or group of processes. Groups of processes were combined when fewer than three companies provided data for a process or when confidentiality agreements precluded presenting individual process data. The manufacturing process groups are presented in Table

2-35. Also for confidentiality purposes, upstream and EOL data (derived from *Ecobilan's* data) were not broken down by process. Burrowing further into the contributing processes or process groups is necessary for future manufacturing improvement assessments. Burrowing further into process-specific data at the use stage is not necessary because electricity generation is the only process in the use stage.

Table 2-35. CRT process groups

Process group	Process(es) included
Monitor assembly	monitor assembly
Tube	CRT (tube) manufacturing
Glass/frit	CRT glass manufacturing, frit manufacturing
PWB	PWB manufacturing
Japanese grid	electricity generation - Japanese electric grid
U.S. grid	electricity generation - U.S. electric grid
Fuels	production of fuel oils #2, #4 and #6, LPG, and natural gas

Tables 2-36 through 2-44 list the specific inventories for each process group in the manufacturing stage for each input and output type. Figures 2-24 through 2-34 graph the total inventories for each process group for each input and output type. It should be noted that the input/output type that had the greatest contribution in the manufacturing stage compared to other stages was fuel inputs, which also translated into total energy inputs being greatest in the manufacturing stage. Nonetheless, for purposes of showing more detail in the manufacturing stage and allowing for improvement assessments for manufacturers, the individual material contributions for each manufacturing process group are presented below.

Of the total 421 kg of primary materials per functional unit in the manufacturing stage, fuels production contributes the greatest (374 kg/functional unit), followed by monitor assembly (20.1 kg/functional unit), and then tube manufacturing (11.9 kg/functional unit) (Figure 2-24). The specific material contributions are presented in Table 2-36. Only small amounts of ancillary materials are used in the CRT life cycle and the manufacturing stage only contributed a small percentage of the overall ancillary materials in the life-cycle. However, within the manufacturing life-cycle stage, fuels production and PWB manufacturing had the greatest amount of ancillary materials (1.16 kg/functional unit each) (Figure 2-25).

Table 2-36. CRT manufacturing stage primary material inputs

Material	Quantity (kg/ (functional unit)	% of process group total	% of grand total
Process group			
Monitor assembly			
ABS resin	4.24e-01	2.11%	
Aluminum (elemental)	3.60e-01	1.79%	
Audio cable assembly	9.45e-02	0.47%	
Cables/wires	6.12e-02	0.31%	
Cables/wires	3.33e-01	1.66%	
Cathode ray tube (CRT)	1.07e+01	53.30%	
Connector	5.67e-02	0.28%	
CRT magnet assembly	7.56e-02	0.38%	
CRT shield assembly - ASTM A366/CC#2	2.42e-01	1.21%	
Deflection Yoke assembly	1.51e-01	0.75%	
Demagnetic coil - PU coated paper	1.26e-01	0.63%	
Ferrite	1.70e-01	0.85%	
Phosphate ester	8.31e-03	0.04%	
Polycarbonate resin	9.23e-01	4.60%	
Polystyrene (PS, high impact)	1.51e-01	0.75%	
Power cord assembly	1.13e-01	0.57%	
PPE	7.35e-01	3.66%	
Printed wiring board (PWB)	8.47e-01	4.22%	
Solder, unspecified	2.67e-02	0.13%	
Steel	3.45e+00	17.21%	
Styrene-butadiene copolymers	8.27e-01	4.13%	
Tricresyl phosphate	2.30e-02	0.11%	
Triphenyl phosphate	5.29e-02	0.26%	
Video cable assembly	1.13e-01	0.57%	
Total	**2.01e+01**	100.00%	**4.76%**
Tube			
Amyl acetate (mixed isomers)	1.20e-03	0.01%	
Aquadag	2.06e-02	0.17%	
Blue Phosphor (ZnS)	3.84e-03	0.03%	
Blue Phosphor (ZnS.Ag.Al)	1.67e-03	0.01%	
CRT glass, unspecified	9.76e+00	81.70%	
Electron gun	1.01e-01	0.84%	
Frit	6.67e-02	0.56%	
Green Phosphor (ZnS)	3.34e-03	0.03%	
Green Phosphor (ZnS.Cu.Al)	1.34e-03	0.01%	
Nickel Alloy (invar)	2.72e-01	2.28%	
Red Phosphor (Y2O2S)	4.65e-03	0.04%	
Red Phosphor (Y2O2S.Eu)	1.33e-03	0.01%	
Steel	1.71e+00	14.30%	
Total	**1.19e+01**	100.00%	**2.84%**

Table 2-36. CRT manufacturing stage primary material inputs

Material	Quantity (kg/ (functional unit)	% of process group total	% of grand total
Process group			
Glass/frit			
Barium Carbonate	2.97e-01	4.52%	
Glass, unspecified	4.91e-02	0.75%	
Lead	4.47e-01	6.82%	
Potassium Carbonate	3.78e-01	5.76%	
Recycled CRT Glass	2.06e+00	31.37%	
Sand	2.40e+00	36.57%	
Sodium Carbonate	4.88e-01	7.43%	
Strontium Carbonate	3.31e-01	5.05%	
Zircon Sand	5.43e-02	0.83%	
Borax	8.00e-03	0.12%	
Lead	4.67e-02	0.71%	
Silica	5.33e-03	0.08%	
Total	**6.56e+00**	100.00%	**1.56%**
PWB			
PWB-laminate	8.47e-01	94.35%	
Solder (63% tin; 37% lead)	5.08e-02	5.66%	
Total	**8.98e-01**	100.00%	**0.21%**
Japanese grid			
Coal, average (in ground)	2.28e+00	47.41%	
Natural gas	1.25e+00	25.89%	
Petroleum (in ground)	1.29e+00	26.69%	
Uranium, yellowcake	3.04e-04	0.01%	
Total	**4.82e+00**	100.00%	**1.14%**
U.S. grid			
Coal, average (in ground)	2.86e+00	90.97%	
Natural gas	2.23e-01	7.10%	
Petroleum (in ground)	6.07e-02	1.93%	
Uranium, yellowcake	7.74e-05	<0.01%	
Total	**3.15e+00**	100.01%	**0.75%**
Fuels			
Petroleum (in ground)	3.70e+02	99.12%	
Natural gas (in ground)	3.27e+00	0.88%	
Total	**3.74e+02**	100.00%	**88.74%**
Grand Total	**4.21e+02**		**100.00%**

Table 2-37. CRT manufacturing stage ancillary material inputs

Material	Quantity (kg/ (functional unit)	% of process group total	% of grand total
Process group			
Monitor assembly			
2,2,4-trimethylpentane	1.50e-04	0.72%	
Cyclohexane	1.88e-04	0.90%	
Fluorocarbon resin	3.75e-05	0.18%	
Isopropyl alcohol	1.94e-02	93.40%	
Surfactant, unspecified	1.42e-04	0.68%	
Synthetic resin, unspecified	8.53e-04	4.10%	
Total	**2.08e-02**	**4.79%**	**0.59%**
Tube			
Acetone	3.17e-04	0.04%	
Acrylic Polymer, unspecified	9.13e-03	1.02%	
Alkali cleaning agent	7.72e-02	8.61%	
Alkali soda (to neutralize acid waste water)	5.45e-02	6.08%	
Ammonia	1.19e-04	0.01%	
Ammonium bifluoride	2.04e-03	0.23%	
Ammonium Dichromate	3.50e-05	<0.01%	
Ammonium fluoride	8.91e-04	0.10%	
Ammonium hydroxide	1.41e-03	0.16%	
Ammonium Oxalate	8.92e-05	0.01%	
Ammonium Oxalate Monohydrate	3.16e-04	0.04%	
Boric acid	4.73e-03	0.53%	
Calcium Chloride	1.27e-01	14.18%	
Calcium hydroxide	9.54e-02	10.64%	
Chlorine	4.03e-02	4.50%	
Chromium (VI)	7.63e-05	0.01%	
Dimethyl Formamide	4.36e-05	<0.01%	
Ferric chloride	1.37e-01	15.32%	
HV Carbon (paste)	1.14e-05	<0.01%	
Hydrochloric acid	4.39e-02	4.89%	
Hydrofluoric acid	7.39e-03	0.82%	
Hydrogen peroxide	5.34e-02	5.96%	
Isopentylacetate	1.74e-03	0.19%	
Muratic Acid (drum)	1.87e-03	0.21%	
Nitric acid	8.17e-03	0.91%	
Nitrogen	4.57e-02	5.10%	
Oxalic acid	5.35e-05	0.01%	
Oxygen (Liquid)	7.57e-03	0.84%	
Periodic Acid	2.26e-04	0.03%	
Polyvinyl alcohol	8.11e-03	0.90%	
Polyvinyl Pyrrolidone (PVP)	2.41e-02	2.69%	
Sodium Dichromate	1.05e-04	0.01%	
Sodium Dichromate Dihydrate (VI)	3.10e-05	<0.01%	

Table 2-37. CRT manufacturing stage ancillary material inputs

Material	Quantity (kg/ (functional unit)	% of process group total	% of grand total
Process group			
Sodium hydroxide	3.52e-03	0.39%	
Sodium Hypochlorite	9.25e-05	0.01%	
Sodium Metabisulfite	4.67e-03	0.52%	
Sodium Persulfate	3.54e-04	0.04%	
Sulfuric acid	5.58e-02	6.23%	
Sulfuric acid, aluminum salt	6.75e-02	7.53%	
Toluene	4.80e-03	0.54%	
unspecified CRT process material	5.77e-03	0.64%	
Xylene (mixed isomers)	4.80e-04	0.05%	
Total	**8.97e-01**	**100.00%**	**25.36%**
Glass/frit			
Aluminum Oxide	3.37e-02	17.30%	
Cerium Oxide	3.28e-03	1.68%	
Chromium Oxide	5.62e-05	0.03%	
Hydrofluoric acid	7.91e-02	40.61%	
Pumice	7.86e-02	40.37%	
Total	**1.95e-01**	**100.00%**	**5.51%**
PWB			
Ammonium chloride	7.76e-02	6.68%	
Ammonium hydroxide	7.76e-02	6.68%	
Formaldehyde	6.60e-03	0.57%	
Glycol ethers	2.35e-02	2.03%	
Hydrochloric acid	1.92e-01	16.51%	
Hydrogen peroxide	3.10e-02	2.67%	
Nitric acid	1.36e-01	11.70%	
Polyethylene glycol	5.04e-02	4.34%	
Potassium hydroxide	4.27e-02	3.68%	
Potassium permanganate	1.16e-03	0.10%	
Potassium peroxymonosulfate	7.06e-02	6.08%	
PWB-solder mask solids	4.37e-02	3.76%	
Sodium Carbonate	3.22e-02	2.77%	
Sodium hydroxide	1.94e-01	16.71%	
Sulfuric acid	1.83e-01	15.72%	
Total	**1.16e+00**	**100.00%**	**32.84%**
Japanese grid			
Lime	1.35e-02	30.57%	
Limestone	3.06e-02	69.43%	
Total	**4.41e-02**	100.00%	**1.25%**
U.S. grid			
Lime	1.69e-02	30.52%	
Limestone	3.85e-02	69.48%	

Table 2-37. CRT manufacturing stage ancillary material inputs

Material	Quantity (kg/ (functional unit)	% of process group total	% of grand total
Process group			
Total	**5.53e-02**	100.00%	**1.57%**
Fuels			
Bauxite (Al2O3, ore)	4.47e-02	3.85%	
Limestone (CaCO3, in ground)	1.08e+00	92.71%	
Sand (in ground)	2.74e-02	2.36%	
Sodium chloride (NaCl, in ground or in sea)	1.26e-02	1.08%	
Total	**1.16e+00**	100.00%	**32.89%**
Grand Total	**3.54e+00**		**100.00%**

Table 2-38. CRT manufacturing stage utility inputs

Material	**Quantity**	**% of process group total**	**% of grand total**
Process group			
Fuels (kg/functional unit):			
Monitor assembly			
Fuel oil #4	**??**		**ERR**
Tube			
Fuel oil #6	3.68e+00	75.86%	
LNG	3.35e-01	6.91%	
Natural gas	8.37e-01	17.23%	
Total	**4.86e+00**	100.00%	**1.14%**
Glass/frit			
Fuel oil #2	1.16e+00	0.33%	
Liquified petroleum gas (LPG)	3.51e+02	99.33%	
Natural gas	1.21e+00	0.34%	
Total	**3.53e+02**	100.00%	**82.72%**
PWB			
Natural gas	**??**		**ERR**
Fuels			
Coal, average (in ground)	1.36e+01	19.71%	
Natural gas (in ground)	4.56e+01	66.20%	
Petroleum (in ground)	9.71e+00	14.08%	
Uranium (U, ore)	2.29e-04	<0.01%	
Total	**6.89e+01**	100.01%	**16.14%**
Grand Total	**4.27e+02**		**100.00%**
Electricity (MJ/functional unit):			
Monitor assembly	1.33e+01		10.27%
Tube	3.19e+01		24.68%
Glass/frit	7.40e+01		57.27%
PWB	1.00e+01		7.77%
Total	**1.29e+02**		**100.00%**
Water (kg or L/functional unit):			
Monitor assembly	3.51e+01		0.31%
Tube	8.11e+02		7.09%
Glass/frit	0		0.00%
PWB	4.22e+01		0.37%
Japanese grid	4.43e+01		0.39%
U.S. grid	1.82e+01		0.16%
Fuels	1.05e+04		91.69%
Total	**1.14e+04**		**100.00%**
Total energy (fuels and electricity, MJ/functional unit):			
Monitor assembly	1.90e+01		0.10%
Tube	2.37e+02		1.29%

Table 2-38. CRT manufacturing stage utility inputs

Material	Quantity	% of process group total	% of grand total
Process group			
Glass/frit	1.52e+04		83.23%
PWB	2.74e+01		0.15%
Fuels	2.79e+03		15.22%
Total	**1.83e+04**		**100.00%**

Table 2-39. CRT manufacturing stage air emissions

Material	Quantity (kg/ (functional unit)	% of process group total	% of grand total
Process group			
Tube			
Carbon monoxide	1.70E-02	50.61%	
Dimethyl Formamide	3.49E-05	0.10%	
Nitrogen oxides	2.17E-03	6.48%	
Nonmethane hydrocarbons, remaining unspeciated	1.59E-04	0.47%	
Sulfur oxides	9.96E-03	29.73%	
Toluene	3.84E-03	11.46%	
Xylene (mixed isomers)	3.84E-04	1.15%	
Total	**3.35E-02**	100.00%	**0.02%**
Glass/frit			
Barium	9.33E-10	<0.01%	
Carbon dioxide	2.85E+00	98.45%	
Carbon monoxide	1.64E-04	0.01%	
Chromium	1.39E-07	<0.01%	
Cobalt	1.43E-10	<0.01%	
Copper	6.33E-10	<0.01%	
Fluorides (F-)	2.93E-05	<0.01%	
Lead	3.22E-07	<0.01%	
Manganese	4.67E-10	<0.01%	
Nickel	5.33E-10	<0.01%	
Nitrogen oxides	4.47E-02	1.54%	
PM	1.10E-04	<0.01%	
Sulfur oxides	5.08E-05	<0.01%	
Zinc (elemental)	4.67E-09	<0.01%	
Total	**2.90E+00**	1.57%	**1.59%**
PWB			
Formaldehyde	**3.88E-05**		**0.00%**
Japanese grid			
1,1,1-Trichloroethane	6.46E-08	<0.01%	
1,2-Dichloroethane	4.57E-08	<0.01%	
2,3,7,8-TCDD	1.68E-14	<0.01%	
2,3,7,8-TCDF	5.84E-14	<0.01%	
2,4-Dinitrotoluene	3.19E-10	<0.01%	
2-Chloroacetophenone	8.00E-09	<0.01%	
2-Methylnaphthalene	2.38E-10	<0.01%	
5-Methyl chrysene	2.51E-11	<0.01%	
Acenaphthene	4.32E-09	<0.01%	
Acenaphthylene	3.29E-10	<0.01%	
Acetaldehyde	6.52E-07	<0.01%	
Acetophenone	1.71E-08	<0.01%	
Acrolein	3.31E-07	<0.01%	
Anthracene	4.55E-10	<0.01%	

Table 2-39. CRT manufacturing stage air emissions

Material	Quantity (kg/ (functional unit)	% of process group total	% of grand total
Process group			
Antimony	9.50E-07	<0.01%	
Arsenic	7.01E-07	<0.01%	
Barium	5.18E-07	<0.01%	
Benzene	1.52E-06	<0.01%	
Benzo[a]anthracene	8.00E-10	<0.01%	
Benzo[a]pyrene	4.35E-11	<0.01%	
Benzo[b,j,k]fluoranthene	3.89E-10	<0.01%	
Benzo[g,h,i]perylene	4.30E-10	<0.01%	
Benzyl chloride	8.00E-07	<0.01%	
Beryllium	3.23E-08	<0.01%	
Biphenyl	1.94E-09	<0.01%	
Bromoform	4.46E-08	<0.01%	
Bromomethane	1.83E-07	<0.01%	
Cadmium	1.41E-07	<0.01%	
Carbon dioxide	1.54E+01	99.14%	
Carbon disulfide	1.49E-07	<0.01%	
Carbon monoxide	2.80E-03	0.02%	
Chloride ions	6.14E-05	<0.01%	
Chlorobenzene	2.51E-08	<0.01%	
Chloroform	6.74E-08	<0.01%	
Chromium (III)	5.52E-07	<0.01%	
Chromium (VI)	1.34E-07	<0.01%	
Chrysene	5.35E-10	<0.01%	
Cobalt	1.18E-06	<0.01%	
Copper	3.18E-07	<0.01%	
Cumene hydroperoxide	6.06E-09	<0.01%	
Cyanide (-1)	2.86E-06	<0.01%	
Di(2-ethylhexyl)phthalate	8.34E-08	<0.01%	
Dibenzo[a,h]anthracene	2.96E-10	<0.01%	
Dichloromethane	3.31E-07	<0.01%	
Dimethyl sulfate	5.49E-08	<0.01%	
Dioxins, remaining unspeciated	7.46E-13	<0.01%	
Ethyl Chloride	4.80E-08	<0.01%	
Ethylbenzene	1.19E-07	<0.01%	
Ethylene dibromide	1.37E-09	<0.01%	
Fluoranthene	1.75E-09	<0.01%	
Fluorene	1.83E-09	<0.01%	
Fluorides (F-)	6.60E-06	<0.01%	
Formaldehyde	1.02E-05	<0.01%	
Furans, remaining unspeciated	1.19E-12	<0.01%	

Table 2-39. CRT manufacturing stage air emissions

Material	Quantity (kg/ (functional unit)	% of process group total	% of grand total
Process group			
Hexane	7.66E-08	<0.01%	
Hydrochloric acid	1.37E-03	<0.01%	
Hydrofluoric acid	1.71E-04	<0.01%	
Indeno(1,2,3-cd)pyrene	4.48E-10	<0.01%	
Isophorone	6.63E-07	<0.01%	
Lead (Pb, ore)	4.41E-07	<0.01%	
Magnesium	1.26E-05	<0.01%	
Manganese (Mn, ore)	1.09E-06	<0.01%	
Mercury	1.18E-07	<0.01%	
Methane	8.13E-05	<0.01%	
Methyl chloride	6.06E-07	<0.01%	
Methyl ethyl ketone	4.46E-07	<0.01%	
Methyl hydrazine	1.94E-07	<0.01%	
Methyl methacrylate	2.29E-08	<0.01%	
Methyl tert-butyl ether	3.99E-08	<0.01%	
Molybdenum	1.55E-07	<0.01%	
Naphthalene	2.21E-07	<0.01%	
Nickel	1.47E-05	<0.01%	
Nitrogen oxides	4.07E-02	0.26%	
Nitrous oxide	1.12E-04	<0.01%	
o-xylene	1.93E-08	<0.01%	
Phenanthrene	5.21E-09	<0.01%	
Phenol	1.83E-08	<0.01%	
PM-10	2.00E-03	0.01%	
Propionaldehyde	4.34E-07	<0.01%	
Pyrene	1.26E-09	<0.01%	
Selenium	1.61E-06	<0.01%	
Styrene	2.86E-08	<0.01%	
Sulfur dioxide	8.62E-02	0.56%	
Tetrachloroethylene	4.92E-08	<0.01%	
TOCs, remaining unspeciated	1.97E-04	<0.01%	
Toluene	1.43E-06	<0.01%	
Vanadium	5.71E-06	<0.01%	
Vinyl acetate	8.67E-09	<0.01%	
Xylene (mixed isomers)	4.23E-08	<0.01%	
Zinc (elemental)	5.15E-06	<0.01%	
Total	**1.55E+01**	100.00%	**8.50%**
U.S. grid			
1,1,1-Trichloroethane	3.06E-08	<0.01%	
1,2-Dichloroethane	5.73E-08	<0.01%	
2,3,7,8-TCDD	2.05E-14	<0.01%	

Table 2-39. CRT manufacturing stage air emissions

Material	Quantity (kg/ (functional unit)	% of process group total	% of grand total
Process group			
2,3,7,8-TCDF	7.30E-14	<0.01%	
2,4-Dinitrotoluene	4.01E-10	<0.01%	
2-Chloroacetophenone	1.00E-08	<0.01%	
2-Methylnaphthalene	4.26E-11	<0.01%	
5-Methyl chrysene	3.15E-11	<0.01%	
Acenaphthene	9.06E-10	<0.01%	
Acenaphthylene	3.60E-10	<0.01%	
Acetaldehyde	8.16E-07	<0.01%	
Acetophenone	2.15E-08	<0.01%	
Acrolein	4.15E-07	<0.01%	
Anthracene	3.11E-10	<0.01%	
Antimony	6.96E-08	<0.01%	
Arsenic	5.99E-07	<0.01%	
Barium	3.28E-08	<0.01%	
Benzene	1.86E-06	<0.01%	
Benzo[a]anthracene	1.48E-10	<0.01%	
Benzo[a]pyrene	5.44E-11	<0.01%	
Benzo[b,j,k]fluoranthene	1.70E-10	<0.01%	
Benzo[g,h,i]perylene	5.75E-11	<0.01%	
Benzyl chloride	1.00E-06	<0.01%	
Beryllium	3.05E-08	<0.01%	
Biphenyl	2.43E-09	<0.01%	
Bromoform	5.58E-08	<0.01%	
Bromomethane	2.29E-07	<0.01%	
Cadmium	7.69E-08	<0.01%	
Carbon dioxide	7.10E+00	98.98%	
Carbon disulfide	1.86E-07	<0.01%	
Carbon monoxide	1.29E-03	0.02%	
Chloride ions	2.90E-06	<0.01%	
Chlorobenzene	3.15E-08	<0.01%	
Chloroform	8.45E-08	<0.01%	
Chromium (III)	3.88E-07	<0.01%	
Chromium (VI)	1.15E-07	<0.01%	
Chrysene	1.63E-10	<0.01%	
Cobalt	1.94E-07	<0.01%	
Copper	1.59E-08	<0.01%	
Cumene	7.59E-09	<0.01%	
Cyanide (-1)	3.58E-06	<0.01%	
Di(2-ethylhexyl)phthalate	1.04E-07	<0.01%	
Dibenzo[a,h]anthracene	1.40E-11	<0.01%	
Dichloromethane	4.15E-07	<0.01%	

Table 2-39. CRT manufacturing stage air emissions

Material	Quantity (kg/ (functional unit)	% of process group total	% of grand total
Process group			
Dimethyl sulfate	6.87E-08	<0.01%	
Dioxins, remaining unspeciated	9.33E-13	<0.01%	
Ethyl Chloride	6.01E-08	<0.01%	
Ethylbenzene	1.35E-07	<0.01%	
Ethylene dibromide	1.72E-09	<0.01%	
Fluoranthene	1.07E-09	<0.01%	
Fluorene	1.34E-09	<0.01%	
Fluoride	3.12E-07	<0.01%	
Formaldehyde	1.35E-06	<0.01%	
Furans, remaining unspeciated	1.49E-12	<0.01%	
Hexane	9.59E-08	<0.01%	
Hydrochloric acid	1.72E-03	0.02%	
Hydrofluoric acid	2.15E-04	<0.01%	
Indeno(1,2,3-cd)pyrene	1.05E-10	<0.01%	
Isophorone	8.30E-07	<0.01%	
Lead	2.04E-07	<0.01%	
Magnesium	1.57E-05	<0.01%	
Manganese	7.28E-07	<0.01%	
Mercury	1.20E-07	<0.01%	
Methane	1.03E-02	0.14%	
Methyl chloride	7.59E-07	<0.01%	
Methyl ethyl ketone	5.58E-07	<0.01%	
Methyl hydrazine	2.43E-07	<0.01%	
Methyl methacrylate	2.86E-08	<0.01%	
Methyl tert-butyl ether	5.01E-08	<0.01%	
Molybdenum	9.32E-09	<0.01%	
Naphthalene	2.92E-08	<0.01%	
Nickel	1.09E-06	<0.01%	
Nitrogen oxides	1.88E-02	0.26%	
Nitrous oxide	5.42E-05	<0.01%	
o-xylene	9.11E-10	<0.01%	
Phenanthrene	4.00E-09	<0.01%	
Phenol	2.29E-08	<0.01%	
Phosphorus (yellow or white)	7.91E-08	<0.01%	
PM-10	9.22E-04	0.01%	
Propionaldehyde	5.44E-07	<0.01%	
Pyrene	5.32E-10	<0.01%	
Selenium	1.87E-06	<0.01%	
Styrene	3.58E-08	<0.01%	
Sulfur dioxide	3.98E-02	0.56%	
Tetrachloroethylene	6.16E-08	<0.01%	

Table 2-39. CRT manufacturing stage air emissions

Material	Quantity (kg/ (functional unit)	% of process group total	% of grand total
Process group			
TOCs, remaining unspeciated	9.19E-05	<0.01%	
Toluene	4.06E-07	<0.01%	
Vanadium	2.81E-07	<0.01%	
Vinyl acetate	1.09E-08	<0.01%	
Xylene (mixed isomers)	5.30E-08	<0.01%	
Zinc (elemental)	2.43E-07	<0.01%	
Total	**7.17E+00**	100.00%	**3.93%**
Fuels			
1,1,1-Trichloroethane	1.36E-07	<0.01%	
1,2-Dichloroethane	2.71E-07	<0.01%	
1,4-Dichlorobenzene	3.06E-07	<0.01%	
2,4-Dinitrotoluene	1.90E-09	<0.01%	
2-Chloroacetophenone	4.75E-08	<0.01%	
2-Methylnaphthalene	6.11E-09	<0.01%	
3-Methylcholanthrene	4.59E-10	<0.01%	
5-Methyl chrysene	1.49E-10	<0.01%	
Acenaphthene	5.31E-09	<0.01%	
Acenaphthylene	2.17E-09	<0.01%	
Acetaldehyde	3.86E-06	<0.01%	
Acetophenone	1.02E-07	<0.01%	
Acrolein	1.97E-06	<0.01%	
Aldehydes	1.52E-03	<0.01%	
Aluminum (elemental)	1.98E-05	<0.01%	
Ammonia	2.35E-03	<0.01%	
Anthracene	2.12E-09	<0.01%	
Antimony	6.36E-07	<0.01%	
Aromatic hydrocarbons	5.29E-08	<0.01%	
Arsenic	1.41E-05	<0.01%	
Barium	3.33E-07	<0.01%	
Benzene	1.57E-02	0.01%	
Benzo[a]anthracene	1.27E-09	<0.01%	
Benzo[a]pyrene	6.94E-10	<0.01%	
Benzo[b,j,k]fluoranthene	7.46E-10	<0.01%	
Benzo[b]fluoranthene	5.07E-10	<0.01%	
Benzo[g,h,i]perylene	5.63E-10	<0.01%	
Benzo[k]fluoranthene	5.07E-10	<0.01%	
Benzyl chloride	4.75E-06	<0.01%	
Beryllium	1.42E-06	<0.01%	
Biphenyl	1.15E-08	<0.01%	
Bromoform	2.64E-07	<0.01%	
Bromomethane	1.08E-06	<0.01%	

Table 2-39. CRT manufacturing stage air emissions

Material	Quantity (kg/ (functional unit)	% of process group total	% of grand total
Process group			
Butane	5.35E-04	<0.01%	
Cadmium	8.20E-07	<0.01%	
Calcium	1.72E-05	<0.01%	
Carbon dioxide	1.54E+02	97.92%	
Carbon disulfide	8.81E-07	<0.01%	
Carbon monoxide	4.36E-01	0.28%	
Chloride ions	3.39E-05	<0.01%	
Chlorine	5.84E-09	<0.01%	
Chlorobenzene	1.49E-07	<0.01%	
Chloroform	4.00E-07	<0.01%	
Chromium (III)	2.13E-05	<0.01%	
Chromium (VI)	2.13E-05	<0.01%	
Chrysene	1.22E-09	<0.01%	
Cobalt	2.54E-06	<0.01%	
Copper	1.57E-06	<0.01%	
Cumene	3.59E-08	<0.01%	
Cyanide (-1)	1.69E-05	<0.01%	
Di(2-ethylhexyl)phthalate	4.95E-07	<0.01%	
Dibenzo[a,h]anthracene	3.61E-10	<0.01%	
Dichloromethane	1.97E-06	<0.01%	
Dimethyl sulfate	3.25E-07	<0.01%	
Dimethylbenzanthracene	3.82E-09	<0.01%	
Dioxins, remaining unspeciated	1.10E-10	<0.01%	
Ethane	7.90E-04	<0.01%	
Ethyl Chloride	2.85E-07	<0.01%	
Ethylbenzene	6.44E-07	<0.01%	
Ethylene dibromide	8.14E-09	<0.01%	
Fluoranthene	5.74E-09	<0.01%	
Fluorene	7.03E-09	<0.01%	
Fluorides (F-)	3.84E-06	<0.01%	
Formaldehyde	1.19E-03	<0.01%	
Furans, remaining unspeciated	5.11E-10	<0.01%	
Halogenated hydrocarbons (unspecified)	2.94E-13	<0.01%	
HALON-1301	5.11E-10	<0.01%	
Hexane	4.59E-04	<0.01%	
Hydrocarbons, remaining unspeciated	1.58E-01	0.10%	
Hydrochloric acid	8.14E-03	<0.01%	
Hydrofluoric acid	1.02E-03	<0.01%	
Hydrogen sulfide	3.11E-03	<0.01%	
Indeno(1,2,3-cd)pyrene	9.43E-10	<0.01%	
Iron	3.83E-05	<0.01%	

Table 2-39. CRT manufacturing stage air emissions

Material	Quantity (kg/ (functional unit)	% of process group total	% of grand total
Process group			
Isophorone	3.93E-06	<0.01%	
Lead	1.25E-05	<0.01%	
Magnesium	7.46E-05	<0.01%	
Manganese	2.26E-05	<0.01%	
Mercury	8.81E-07	<0.01%	
Metals, remaining unspeciated	3.16E-07	<0.01%	
Methane	8.98E-01	0.57%	
Methyl chloride	3.59E-06	<0.01%	
Methyl ethyl ketone	2.64E-06	<0.01%	
Methyl hydrazine	1.15E-06	<0.01%	
Methyl methacrylate	1.36E-07	<0.01%	
Methyl tert-butyl ether	2.37E-07	<0.01%	
Molybdenum	1.97E-06	<0.01%	
Naphthalene	3.54E-07	<0.01%	
Nickel	1.24E-04	<0.01%	
Nitrogen oxides	5.88E-01	0.37%	
Nitrous oxide	1.64E-02	0.01%	
Nonmethane hydrocarbons, remaining unspeciated	1.10E-01	0.07%	
n-Propane	1.69E-06	<0.01%	
Other organics	7.83E-02	0.05%	
o-xylene	1.11E-06	<0.01%	
Pentane	6.62E-04	<0.01%	
Phenanthrene	2.30E-08	<0.01%	
Phenol	1.08E-07	<0.01%	
Phosphorus (yellow or white)	1.25E-05	<0.01%	
PM	1.31E-01	0.08%	
PM-10	2.28E-04	<0.01%	
Polycyclic aromatic hydrocarbons	5.87E-11	<0.01%	
Propionaldehyde	2.58E-06	<0.01%	
Pyrene	3.65E-09	<0.01%	
Selenium	9.47E-06	<0.01%	
Silicon	1.72E-05	<0.01%	
Sodium	1.02E-04	<0.01%	
Styrene	1.69E-07	<0.01%	
Sulfur oxides	8.10E-01	0.52%	
Tetrachloroethylene	2.92E-07	<0.01%	
Toluene	3.81E-06	<0.01%	
Vanadium	2.68E-04	<0.01%	

Table 2-39. CRT manufacturing stage air emissions

Material	Quantity (kg/ (functional unit)	% of process group total	% of grand total
Process group			
Vinyl acetate	5.15E-08	<0.01%	
Zinc (elemental)	1.02E-05	<0.01%	
Total	**1.57E+02**	100.00%	**85.96%**
Grand Total	**1.83E+02**		**100.00%**

Table 2-40. CRT manufacturing stage water outputs (wastewaters and pollutants)

Material	Disposition	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process group				
WASTEWATER STREAMS				
Tube				
Wastewater stream	treatment	5.26e+01	9.87%	
Wastewater stream	surface water	4.81e+02	90.13%	
Total		**5.33e+02**	100.00%	**35.42%**
Glass/frit				
Wastewater stream	surface water	**3.62e+01**		**2.40%**
PWB				
Wastewater stream	treatment	**4.22e+01**		**2.80%**
Fuels				
Wastewater stream	surface water	**8.94e+02**		**59.38%**
Grand Total		**1.51e+03**		**100.00%**
WASTEWATER POLLUTANTS				
Tube				
BOD	surface water	6.39e-03	5.34%	
Chromium ore	surface water	1.02e-05	<0.01%	
Chromium ore	treatment	1.03e-06	<0.01%	
COD	surface water	7.22e-03	6.04%	
COD	treatment	8.33e-03	6.97%	
Copper	surface water	1.80e-06	<0.01%	
Cyanide (-1)	surface water	6.06e-07	<0.01%	
Dissolved solids	treatment	8.01e-02	67.03%	
Fluoride	surface water	3.45e-03	2.89%	
Fluoride	treatment	3.51e-04	0.29%	
Iron	surface water	1.65e-04	0.14%	
Lead	surface water	3.01e-06	<0.01%	
Lead	treatment	1.03e-06	<0.01%	
Manganese	surface water	3.60e-06	<0.01%	
Molybdenum	surface water	1.20e-07	<0.01%	
Nickel	surface water	7.93e-05	0.07%	
Nitrogen	surface water	7.18e-03	6.01%	
Oil & grease	surface water	2.41e-04	0.20%	
Phosphate as P2O5	surface water	1.21e-06	<0.01%	
Phosphorus (yellow or white)	surface water	5.05e-05	0.04%	
Suspended solids	surface water	4.63e-03	3.87%	
Suspended solids	treatment	1.28e-03	1.07%	
Zinc (elemental)	surface water	1.39e-05	0.01%	
Zinc (elemental)	treatment	1.03e-06	<0.01%	
Total		**1.20e-01**	100.00%	**2.51%**
Glass/frit				
BOD	surface water	8.20e-06	<0.01%	

Table 2-40. CRT manufacturing stage water outputs (wastewaters and pollutants)

Material	Disposition	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process group				
Chloride ions	surface water	1.01e+00	21.73%	
Chromium	surface water	8.20e-08	<0.01%	
COD	surface water	8.20e-06	<0.01%	
Dissolved solids	surface water	3.62e+00	77.84%	
Fluorides (F-)	surface water	2.93e-03	0.06%	
Iron	surface water	2.77e-03	0.06%	
Lead	surface water	4.34e-05	<0.01%	
Nickel	surface water	8.20e-08	<0.01%	
Nitrates/nitrites	surface water	3.95e-06	<0.01%	
Oil & grease	surface water	7.22e-03	0.16%	
Suspended solids	surface water	7.23e-03	0.16%	
Total		**4.65e+00**	100.00%	**97.45%**
PWB				
Copper (+1 & +2)	treatment	9.71e-05	85.71%	
Lead cmpds	treatment	1.62e-05	14.29%	
Total		**1.13e-04**	100.00%	**0.00%**
Japanese grid				
Sulfate ion (-4)	surface water	8.72e-04	97.46%	
Suspended solids	surface water	2.27e-05	2.54%	
Total		**8.94e-04**	100.00%	**0.02%**
U.S. grid				
Sulfate ion (-4)	treatment	1.09e-03	97.46%	
Suspended solids	treatment	2.84e-05	2.54%	
Total		**1.12e-03**	100.00%	**0.02%**
Fuels				
Acids (H+)	surface water	2.50e-09	<0.01%	
Adsorbable organic halides	surface water	2.27e-15	<0.01%	
Aluminum (+3)	surface water	8.62e-10	<0.01%	
Ammonia ions	surface water	1.01e-07	0.10%	
Aromatic hydrocarbons	surface water	5.33e-13	<0.01%	
Barium cmpds	surface water	1.71e-12	<0.01%	
BOD	surface water	1.21e-06	1.22%	
Cadmium cmpds	surface water	1.78e-15	<0.01%	
Chloride ions	surface water	3.56e-05	36.07%	
Chromium (III)	surface water	3.31e-10	<0.01%	
Chromium (VI)	surface water	3.31e-10	<0.01%	
COD	surface water	9.80e-06	9.92%	
Copper (+1 & +2)	surface water	3.55e-14	<0.01%	
Cyanide (-1)	surface water	2.49e-15	<0.01%	
Dissolved organics	surface water	6.62e-09	<0.01%	
Dissolved solids	surface water	2.21e-07	0.22%	
Fluorides (F-)	surface water	1.80e-08	0.02%	

Table 2-40. CRT manufacturing stage water outputs (wastewaters and pollutants)

Material	Disposition	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process group				
Halogenated matter (organic)	surface water	7.11e-16	<0.01%	
Hydrocarbons, remaining unspeciated	surface water	2.61e-09	<0.01%	
Iron (+2 & +3)	surface water	3.79e-11	<0.01%	
Lead cmpds	surface water	7.11e-15	<0.01%	
Mercury compounds	surface water	8.17e-18	<0.01%	
Metals, remaining unspeciated	surface water	6.27e-08	0.06%	
Nickel cmpds	surface water	3.55e-15	<0.01%	
Nitrate	surface water	4.53e-09	<0.01%	
Other nitrogen	surface water	9.59e-14	<0.01%	
Phenol	surface water	2.21e-08	0.02%	
Phosphates	surface water	2.02e-11	<0.01%	
Polycyclic aromatic hydrocarbons	surface water	8.53e-15	<0.01%	
Salts (unspecified)	surface water	9.83e-09	<0.01%	
Sodium (+1)	surface water	4.59e-05	46.44%	
Sulfate ion (-4)	surface water	4.26e-09	<0.01%	
Sulfide	surface water	1.38e-09	<0.01%	
Suspended solids	surface water	5.19e-06	5.26%	
TOCs	surface water	5.33e-12	<0.01%	
Toluene	surface water	7.82e-14	<0.01%	
Waste oil	surface water	6.26e-07	0.63%	
Zinc (+2)	surface water	1.58e-10	<0.01%	
Total		**9.88e-05**	100.00%	**0.00%**
Grand Total		**4.77e+00**		**100.00%**

Table 2-41. CRT manufacturing stage hazardous waste outputs (kg/functional unit)

Material	Disposition	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process group				
Tube				
Frit	landfill	2.99e-03	15.58%	
Lead sulfate cake	landfill	2.67e-05	0.14%	
Silica coat waste	treatment	2.86e-04	1.49%	
Slag and ash	landfill	2.47e-03	12.90%	
Slurry scrap (chromium-based)	landfill	8.62e-04	4.50%	
Spent solvent, unspecified	treatment	2.75e-04	1.43%	
Unspecified sludge	landfill	5.22e-03	27.26%	
Unspecified sludge	recycling/reuse	5.56e-03	29.03%	
Waste oxygenated solvents	treatment	9.48e-05	0.49%	
Waste water treatment (WWT) filters	landfill	3.40e-04	1.78%	
Total		**1.81e-02**	100.00%	**1.61%**
Glass/frit				
Barium debris (D008 waste)	landfill	2.14e-04	0.59%	
Broken CRT glass	landfill	1.88e-03	5.17%	
Chrome debris (D007 waste)	treatment	1.47e-04	0.41%	
Chrome liquid waste (D007 waste)	recycling/reuse	9.80e-03	26.95%	
cinders from CRT glass mfg (70% PbO)	landfill	8.26e-03	22.71%	
CRT glass faceplate EP dust (Pb) (D008 waste)	landfill	1.03e-03	2.83%	
CRT glass funnel EP dust (Pb) (D008 waste)	recycling/reuse	5.01e-03	13.78%	
Hazardous sludge (Pb) (D008)	landfill	1.52e-03	4.17%	
Hydrofluoric acid	landfill	1.78e-03	4.89%	
Lead contaminated grit (D008 waste)	landfill	3.46e-05	0.10%	
Lead debris (D008 waste)	landfill	2.14e-04	0.59%	
sludge from CRT glass mfg (1% PbO)	landfill	8.77e-04	2.41%	
Waste acid (mostly 3% HCl solution)	recycling/reuse	3.93e-03	10.81%	
Waste Batch (Ba, Pb) (D008 waste)	landfill	1.41e-03	3.89%	
Waste finishing sludge (Pb) (D008 waste)	landfill	2.56e-04	0.70%	
Total		**3.64e-02**	100.00%	**3.23%**
PWB				
General Hazardous Waste	treatment	1.24e-01	27.26%	
PWB-Decontaminating debris	treatment	1.55e-02	3.41%	
PWB-Lead contaminated waste oil	treatment	1.16e-02	2.56%	
PWB-Route dust	recycling/reuse	1.20e-02	2.64%	
PWB-Solder dross	recycling/reuse	6.70e-02	14.72%	
PWB-Waste cupric etchant	recycling/reuse	2.25e-01	49.42%	
Total		**4.55e-01**	100.00%	**40.49%**
Fuels				
Hazardous waste	landfill	**6.15e-01**		**54.67%**

Table 2-41. CRT manufacturing stage hazardous waste outputs (kg/functional unit)

Material	Disposition	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process group				
Grand Total		1.12e+00		100.00%

Table 2-42. CRT manufacturing stage solid waste outputs (kg/functional unit)

Material	Disposition	Quantity(kg/ functional unit)	% of process group total	% of grand total
Process group				
Monitor Assembly				
Broken CRT glass	recycling/reuse	3.82e-01	75.07%	
Cables/wires	recycling/reuse	8.86e-03	1.74%	
Printed wiring board (PWB)	recycling/reuse	3.70e-02	7.28%	
Waste plastics from CRT monitor	recycling/reuse	8.09e-02	15.91%	
Total		**5.09e-01**	100.00%	**0.63%**
Tube				
Broken CRT glass	recycling/reuse	6.94e-01	37.43%	
Ferric chloride	recycling/reuse	3.69e-01	19.93%	
Sludge (aquadag)	landfill	2.22e-03	0.12%	
Sludge (phosphor)	landfill	4.31e-03	0.23%	
Spent solvents (toluene,xylene,dimethyl formamide,isopropyl alcohol)	recycling/reuse	4.17e-02	2.25%	
Unspecified sludge	recycling/reuse	1.26e-01	6.78%	
Waste alkali (cleaning caustic and alkali soda effluent)	recycling/reuse	2.12e-02	1.15%	
Waste metals, unspecified	recycling/reuse	8.79e-02	4.74%	
Waste oil	recycling/reuse	1.43e-03	0.08%	
Waste oil	treatment	2.55e-03	0.14%	
Waste Plastic (packing material)	treatment	3.01e-02	1.63%	
Waste Plastic (styrene foam)	recycling/reuse	3.77e-03	0.20%	
Waste water treatment (WWT) sludge	landfill	8.43e-02	4.55%	
Waste water treatment (WWT) sludge	recycling/reuse	3.72e-01	20.06%	
Wastepaper	recycling/reuse	8.34e-03	0.45%	
Wood, average	landfill	4.94e-03	0.27%	
Total		**1.85e+00**	100.00%	**2.28%**
Glass/frit				
abrasive sludge	recycling/reuse	4.21e-02	11.34%	
acid absorbent	landfill	8.13e-05	0.02%	
blasting media	landfill	3.66e-04	0.10%	
Cobalt nitrate	treatment	6.10e-05	0.02%	
CRT glass, faceplate	landfill	2.43e-02	6.54%	
Diesel fuel	treatment	4.07e-05	0.01%	
Dust	treatment	3.43e-03	0.92%	
Nickel nitrate	treatment	6.10e-05	0.02%	
Oily rags & filter media	landfill	3.25e-04	0.09%	
Oily rags & filter media	recycling/reuse	4.07e-05	0.01%	
parts cleaner solvent	recycling/reuse	8.13e-05	0.02%	
Plating process sludge	landfill	3.28e-04	0.09%	
Potassium Carbonate	landfill	3.30e-03	0.89%	
sludge (calcium fluoride, CaF2)	recycling/reuse	1.75e-02	4.72%	

Table 2-42. CRT manufacturing stage solid waste outputs (kg/functional unit)

Material	Disposition	Quantity(kg/ functional unit)	% of process group total	% of grand total
Process group				
Sodium Carbonate	landfill	3.29e-03	0.89%	
Unspecified sludge	landfill	7.69e-03	2.07%	
Waste alkali, unspecified	treatment	4.21e-05	0.01%	
Waste oil	treatment	6.54e-03	1.76%	
Waste refractory	landfill	2.44e-03	0.66%	
Waste water treatment (WWT) sludge	landfill	2.59e-01	69.68%	
PM	landfill	5.33e-04	0.14%	
Total		**3.72e-01**	100.00%	**0.46%**
PWB				
PWB-Drill dust	landfill	1.49e-02	0.36%	
Unspecified solid waste	recycling/reuse	4.33e-01	10.53%	
Unspecified solid waste	treatment	3.66e+00	89.11%	
Total		**4.11e+00**	100.00%	**5.06%**
Japanese grid				
Coal waste	landfill	6.48e-01	61.12%	
Dust/sludge	landfill	2.50e-01	23.59%	
Fly/bottom ash	landfill	1.62e-01	15.28%	
Total		**1.06e+00**	100.00%	**1.31%**
U.S. grid				
Coal waste	landfill	8.12e-01	61.10%	
Dust/sludge	landfill	3.14e-01	23.63%	
Fly/bottom ash	landfill	2.03e-01	15.27%	
Total		**1.33e+00**	100.00%	**1.64%**
Fuels				
Aluminum scrap	recycling/reuse	1.82e-04	<0.01%	
Aluminum scrap, Wabash 319	recycling/reuse	5.08e-07	<0.01%	
Bauxite residues	landfill	1.21e-02	0.02%	
FGD sludge	landfill	2.14e-01	0.30%	
Mineral waste	landfill	2.61e-03	<0.01%	
Mixed industrial (waste)	landfill	1.00e+00	1.39%	
Non toxic chemical waste (unspecified)	landfill	6.11e-04	<0.01%	
Slag and ash	landfill	6.66e+01	92.62%	
Slag and ash	recycling/reuse	6.85e-01	0.95%	
Unspecified solid waste (incinerated)	treatment	1.33e-02	0.02%	
Unspecified waste	landfill	3.38e+00	4.70%	
Total		**7.19e+01**	100.04%	**88.62%**
Grand Total		**8.12e+01**		**100.00%**

Table 2-43. CRT manufacturing stage radioactive waste outputs

Material	Disposition	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process group				
Japanese grid				
Low-level radioactive waste	landfill	1.10e-04	76.93%	
Uranium, depleted	landfill	3.31e-05	23.07%	
Total		**1.43e-04**	100.00%	**79.72%**
U.S. grid				
Low-level radioactive waste	landfill	2.80e-05	76.93%	
Uranium, depleted	landfill	8.41e-06	23.07%	
Total		**3.65e-05**	100.00%	**20.28%**
Grand Total		**1.80e-04**		**100.00%**

Table 2-44. CRT manufacturing stage radioactivity outputs

Material	Disposition	Quantity (Bq/ functional unit)	% of process group total	% of grand total
Process group				
Japanese grid				
Antimony-124 (isotope)	treatment	4.95e-01	<0.01%	
Antimony-125 (isotope)	treatment	1.97e+00	<0.01%	
Argon-41 (isotope)	air	1.00e+03	0.03%	
Barium-140 (isotope)	treatment	3.67e-02	<0.01%	
Bromine-89 (isotope)	air	1.16e-04	<0.01%	
Bromine-90 (isotope)	air	4.72e-05	<0.01%	
Cesium-134 (isotope)	air	3.18e-03	<0.01%	
Cesium-134 (isotope)	treatment	1.32e+00	<0.01%	
Cesium-137 (isotope)	air	2.40e-02	<0.01%	
Cesium-137 (isotope)	treatment	1.99e+00	<0.01%	
Chromium-51 (isotope)	air	6.29e-02	<0.01%	
Chromium-51 (isotope)	treatment	2.39e+00	<0.01%	
Cobalt-57 (isotope)	air	1.69e-04	<0.01%	
Cobalt-57 (isotope)	treatment	5.78e-02	<0.01%	
Cobalt-58 (isotope)	air	2.16e-03	<0.01%	
Cobalt-58 (isotope)	treatment	2.35e+01	<0.01%	
Cobalt-60 (isotope)	air	1.62e-02	<0.01%	
Cobalt-80 (isotope)	treatment	6.17e+00	<0.01%	
Iodine-131 (isotope)	air	7.58e-02	<0.01%	
Iodine-131 (isotope)	treatment	1.10e+00	<0.01%	
Iodine-132 (isotope)	air	1.54e-02	<0.01%	
Iodine-132 (isotope)	treatment	4.17e-01	<0.01%	
Iodine-133 (isotope)	air	7.03e+01	<0.01%	
Iodine-133 (isotope)	treatment	4.72e-01	<0.01%	
Iodine-134 (isotope)	air	7.98e-02	<0.01%	
Iodine-135 (isotope)	air	4.01e-03	<0.01%	
Iodine-135 (isotope)	treatment	3.38e-01	<0.01%	
Iron-55 (isotope)	treatment	5.62e+00	<0.01%	
Iron-59 (isotope)	treatment	2.88e-01	<0.01%	
Krypton-85 (isotope)	air	1.66e+03	0.06%	
Krypton-85M (isotope)	air	8.06e+01	<0.01%	
Krypton-85M (isotope)	treatment	1.49e+00	<0.01%	
Krypton-87 (isotope)	air	3.00e+01	<0.01%	
Krypton-88 (isotope)	air	1.41e+02	<0.01%	
Lanthanum-140 (isotope)	treatment	3.93e-02	<0.01%	
Manganese-54 (isotope)	air	8.92e-04	<0.01%	
Manganese-54 (isotope)	treatment	1.57e+00	<0.01%	
Molybdenum-99 (isotope)	treatment	2.97e+06	98.42%	
Niobium-95 (isotope)	air	3.54e-05	<0.01%	
Niobium-95 (isotope)	treatment	4.05e-01	<0.01%	
Rubidium-88 (isotope)	air	3.29e-01	<0.01%	

Table 2-44. CRT manufacturing stage radioactivity outputs

Material	Disposition	Quantity (Bq/ functional unit)	% of process group total	% of grand total
Process group				
Ruthenium-103 (isotope)	treatment	4.95e-02	<0.01%	
Silver-110M (isotope)	air	1.06e-06	<0.01%	
Silver-110M (isotope)	treatment	5.78e-01	<0.01%	
Sodium-24 (isotope)	treatment	8.80e-02	<0.01%	
Strontium-89 (isotope)	treatment	9.51e-02	<0.01%	
Strontium-90 (isotope)	treatment	2.24e-02	<0.01%	
Strontium-95 (isotope)	treatment	2.46e-01	<0.01%	
Sulfur-136 (isotope)	treatment	5.30e-02	<0.01%	
Technetium-99M (isotope)	air	4.75e-06	<0.01%	
Technetium-99M (isotope)	treatment	3.45e-02	<0.01%	
Tin-113 (isotope)	treatment	5.46e-02	<0.01%	
Tritium-3 (isotope)	air	2.35e+03	0.08%	
Tritium-3 (isotope)	treatment	1.76e+04	0.58%	
Xenon-131M (isotope)	air	1.36e+02	<0.01%	
Xenon-131M (isotope)	treatment	1.81e+01	<0.01%	
Xenon-133 (isotope)	air	1.30e+03	0.04%	
Xenon-133 (isotope)	treatment	2.78e+03	0.09%	
Xenon-133M (isotope)	air	1.96e+04	0.65%	
Xenon-133M (isotope)	treatment	2.28e+01	<0.01%	
Xenon-135 (isotope)	air	7.39e+02	0.02%	
Xenon-135 (isotope)	treatment	2.07e+01	<0.01%	
Xenon-135M (isotope)	air	1.41e+01	<0.01%	
Xenon-138 (isotope)	air	4.68e+01	<0.01%	
Zinc-85 (isotope)	treatment	2.65e-02	<0.01%	
Zirconium-95 (isotope)	air	9.16e-05	<0.01%	
Total		**3.01e+06**	100.00%	**79.70%**
U.S. grid				
Antimony-124 (isotope)	treatment	1.26e-01	<0.01%	
Antimony-125 (isotope)	treatment	5.02e-01	<0.01%	
Argon-41 (isotope)	air	2.55e+02	0.03%	
Barium-140 (isotope)	treatment	9.33e-03	<0.01%	
Bromine-89 (isotope)	air	2.95e-05	<0.01%	
Bromine-90 (isotope)	air	1.20e-05	<0.01%	
Cesium-134 (isotope)	air	8.09e-04	<0.01%	
Cesium-134 (isotope)	treatment	3.37e-01	<0.01%	
Cesium-136 (isotope)	treatment	1.44e-02	<0.01%	
Cesium-137 (isotope)	air	6.11e-03	<0.01%	
Cesium-137 (isotope)	treatment	5.06e-01	<0.01%	
Chromium-51 (isotope)	air	1.60e-02	<0.01%	
Chromium-51 (isotope)	treatment	6.07e-01	<0.01%	
Cobalt-57 (isotope)	air	4.30e-05	<0.01%	
Cobalt-57 (isotope)	treatment	1.47e-02	<0.01%	

Table 2-44. CRT manufacturing stage radioactivity outputs

Material	Disposition	Quantity (Bq/ functional unit)	% of process group total	% of grand total
Process group				
Cobalt-58 (isotope)	air	5.49e+01	<0.01%	
Cobalt-58 (isotope)	treatment	5.98e+00	<0.01%	
Cobalt-60 (isotope)	air	4.13e-03	<0.01%	
Cobalt-80 (isotope)	treatment	1.57e+00	<0.01%	
Iodine-131 (isotope)	air	1.93e-02	<0.01%	
Iodine-131 (isotope)	treatment	2.80e-01	<0.01%	
Iodine-132 (isotope)	air	3.92e-03	<0.01%	
Iodine-132 (isotope)	treatment	1.06e-01	<0.01%	
Iodine-133 (isotope)	air	1.79e+01	<0.01%	
Iodine-133 (isotope)	treatment	1.20e-01	<0.01%	
Iodine-134 (isotope)	air	2.03e-02	<0.01%	
Iodine-135 (isotope)	air	1.02e-03	<0.01%	
Iodine-135 (isotope)	treatment	8.60e-02	<0.01%	
Iron-55 (isotope)	treatment	1.43e+00	<0.01%	
Iron-59 (isotope)	treatment	7.34e-02	<0.01%	
Krypton-85 (isotope)	air	4.23e+02	0.06%	
Krypton-85M (isotope)	air	2.05e+01	<0.01%	
Krypton-85M (isotope)	treatment	3.78e-01	<0.01%	
Krypton-87 (isotope)	air	7.62e+00	<0.01%	
Krypton-88 (isotope)	air	3.58e+01	<0.01%	
Lanthanum-140 (isotope)	treatment	9.99e-03	<0.01%	
Manganese-54 (isotope)	air	2.27e-04	<0.01%	
Manganese-54 (isotope)	treatment	4.00e-01	<0.01%	
Molybdenum-99 (isotope)	treatment	7.55e+05	98.41%	
Niobium-95 (isotope)	air	9.01e-06	<0.01%	
Niobium-95 (isotope)	treatment	1.03e-01	<0.01%	
Rubidium-88 (isotope)	air	8.37e-02	<0.01%	
Ruthenium-103 (isotope)	treatment	1.26e-02	<0.01%	
Silver-110M (isotope)	air	2.69e-07	<0.01%	
Silver-110M (isotope)	treatment	1.47e-01	<0.01%	
Sodium-24 (isotope)	treatment	2.24e-02	<0.01%	
Strontium-89 (isotope)	treatment	2.42e-02	<0.01%	
Strontium-90 (isotope)	treatment	5.69e-03	<0.01%	
Strontium-95 (isotope)	treatment	6.27e-02	<0.01%	
Sulfur-136 (isotope)	treatment	1.35e-02	<0.01%	
Technetium-99M (isotope)	air	1.21e-06	<0.01%	
Technetium-99M (isotope)	treatment	8.77e-03	<0.01%	
Tin-113 (isotope)	treatment	1.39e-02	<0.01%	
Tritium-3 (isotope)	air	5.98e+02	0.08%	
Tritium-3 (isotope)	treatment	4.47e+03	0.58%	
Xenon-131M (isotope)	air	3.45e+01	<0.01%	
Xenon-131M (isotope)	treatment	4.60e+00	<0.01%	

Table 2-44. CRT manufacturing stage radioactivity outputs

Material	Disposition	Quantity (Bq/ functional unit)	% of process group total	% of grand total
Process group				
Xenon-133 (isotope)	air	4.98e+03	0.65%	
Xenon-133 (isotope)	treatment	7.07e+02	0.09%	
Xenon-133M (isotope)	air	3.31e+02	0.04%	
Xenon-133M (isotope)	treatment	5.79e+00	<0.01%	
Xenon-135 (isotope)	treatment	5.27e+00	<0.01%	
Xenon-135M (isotope)	air	3.59e+00	<0.01%	
Xenon-138 (isotope)	air	1.19e+01	<0.01%	
Zinc-85 (isotope)	treatment	6.75e-03	<0.01%	
Zirconium-95 (isotope)	air	2.33e-05	<0.01%	
Total		**7.67e+05**	100.00%	**20.27%**
Fuels				
Radioactive substance (unspecified)	air	9.19e+02	99.08%	
Radioactive substance (unspecified)	surface water	8.52e+00	0.92%	
Total		**9.27e+02**	100.00%	**0.02%**
Grand Total		**3.78e+06**		**100.00%**

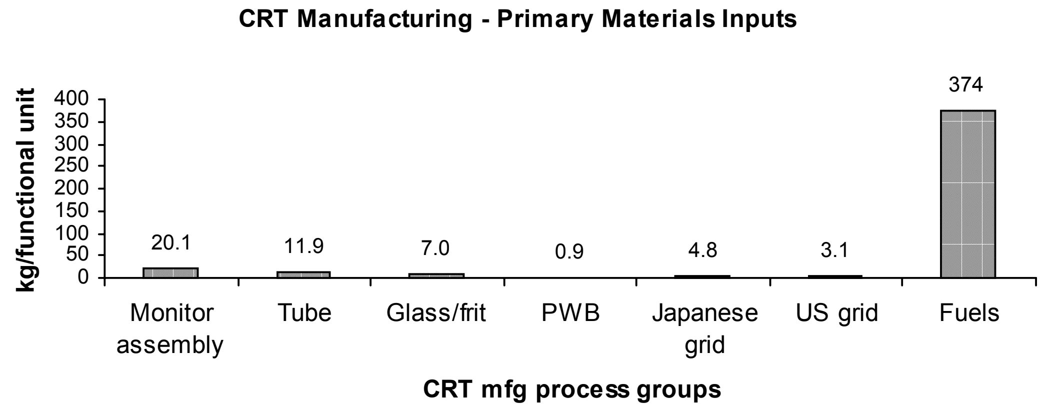

Figure 2-24. CRT manufacturing primary inputs

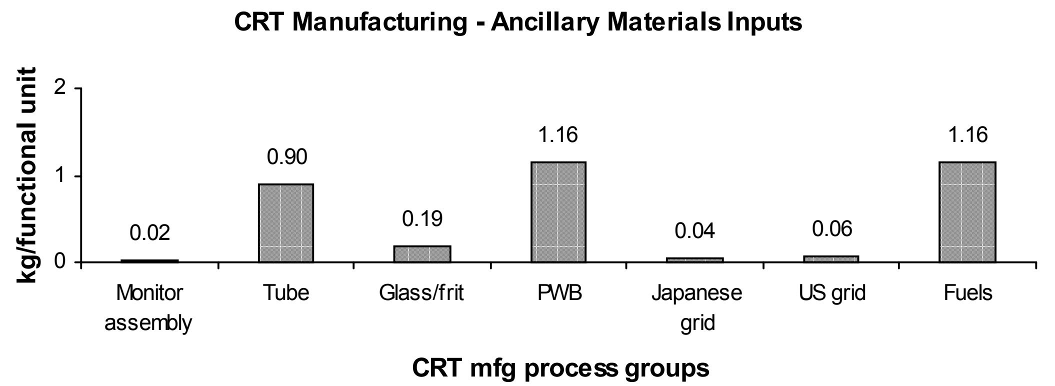

Figure 2-25. CRT manufacturing ancillary inputs

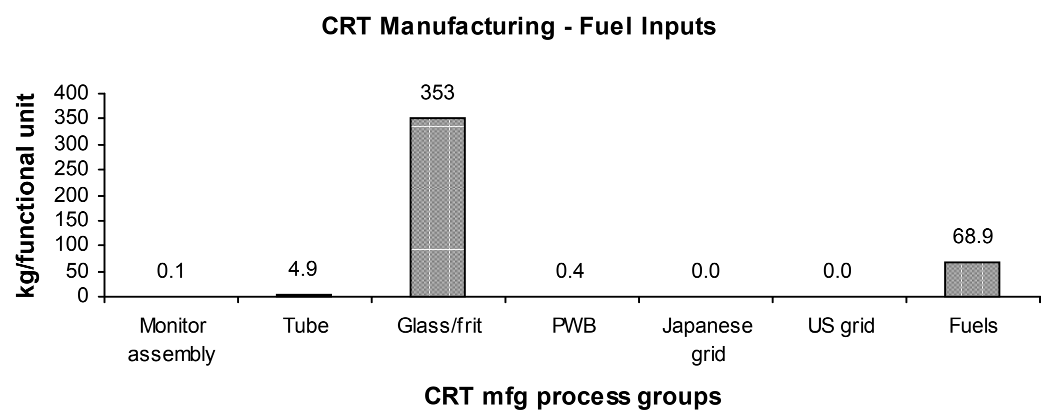

Figure 2-26. CRT manufacturing fuel inputs

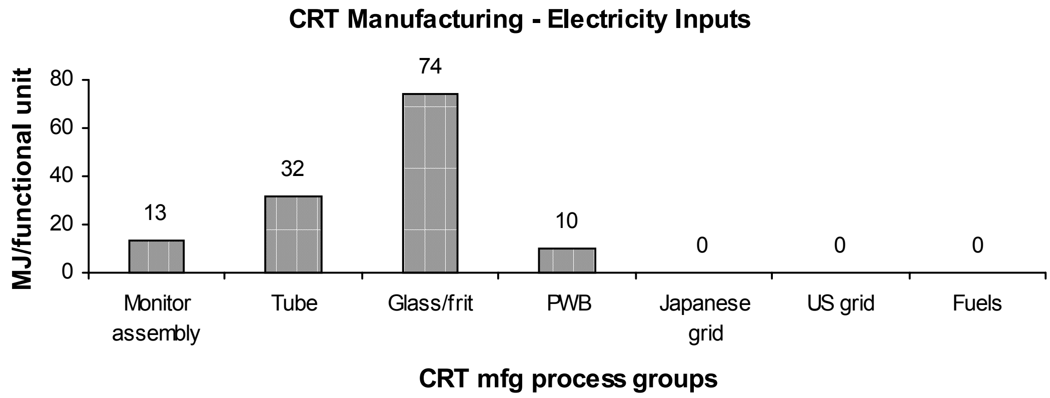

Figure 2-27. CRT manufacturing electricity inputs

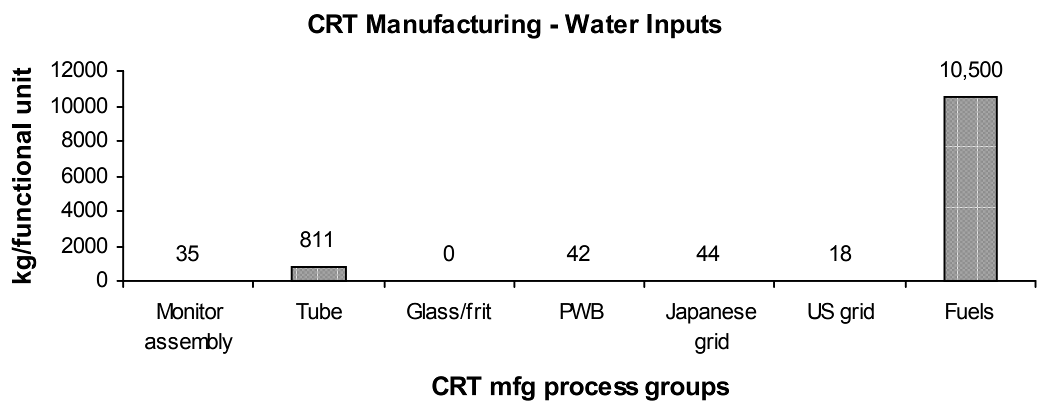

Figure 2-28. CRT manufacturing water inputs

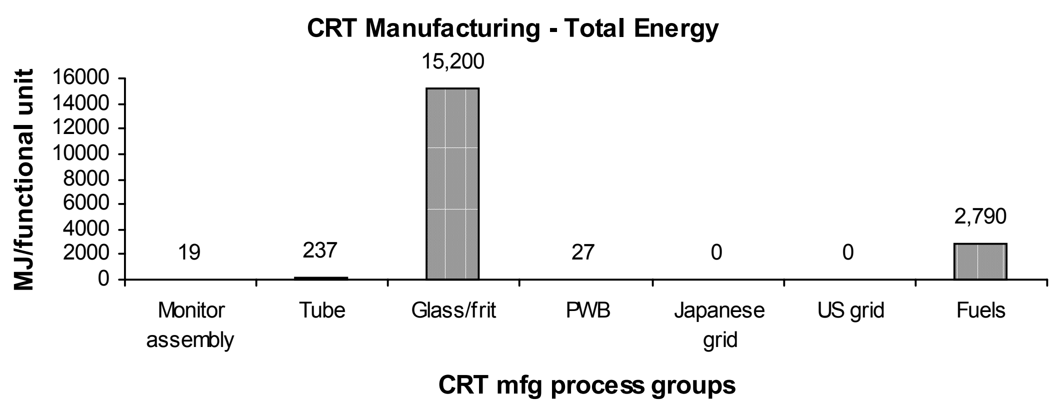

Figure 2-29. CRT manufacturing energy inputs

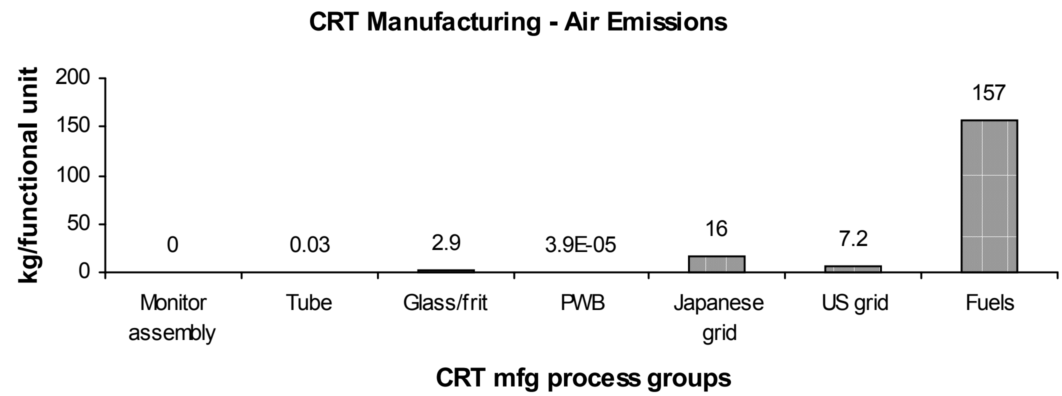

Figure 2-30. CRT manufacturing air emissions

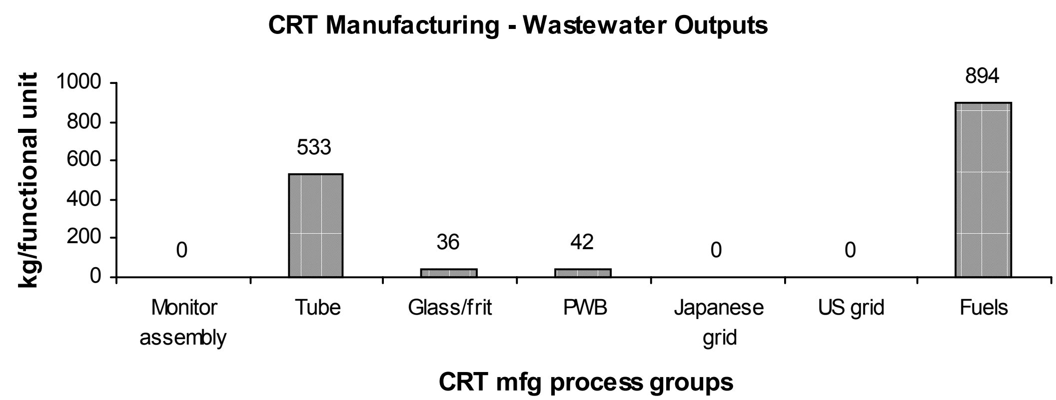

Figure 2-31. CRT manufacturing wastewater outputs

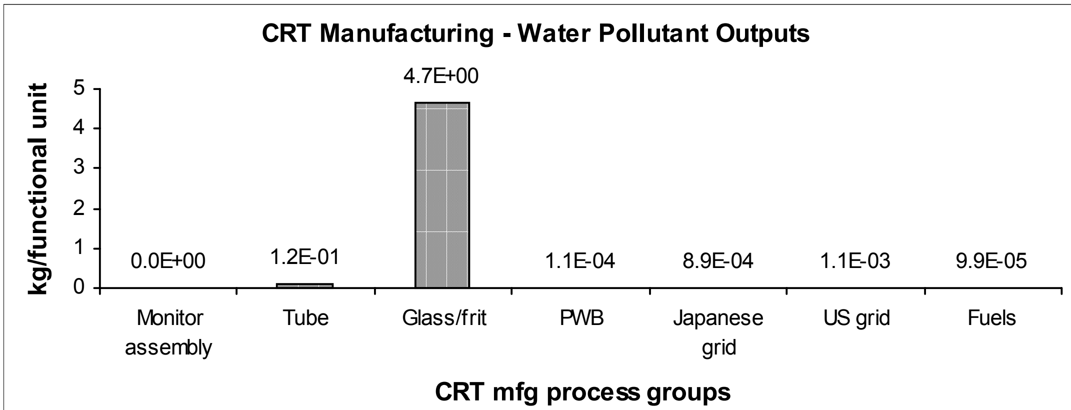

Figure 2-32. CRT manufacturing water pollutant outputs

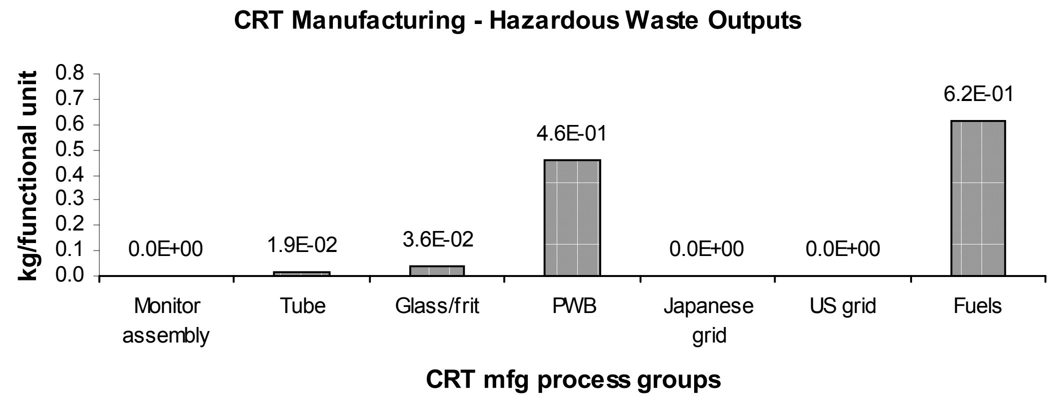

Figure 2-33. CRT manufacturing hazardous waste outputs

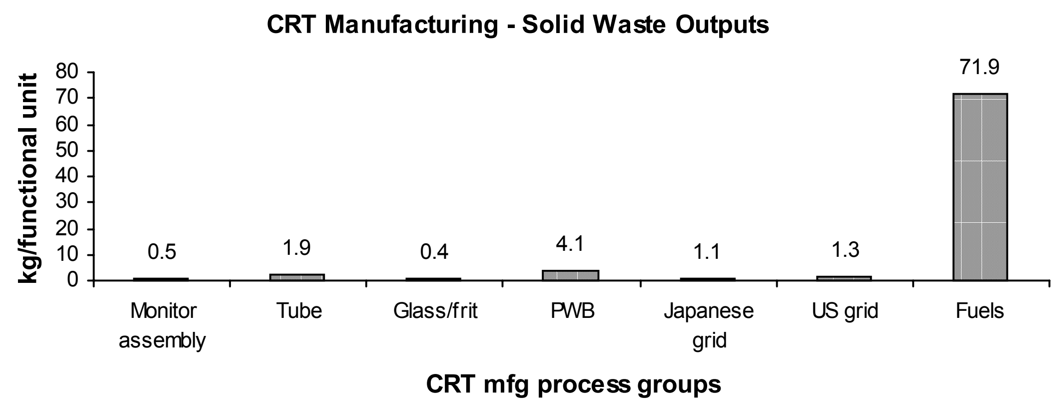

Figure 2-34. CRT manufacturing solid waste outputs

Among the utility inputs, both fuels and electricity were greatest in the glass/frit manufacturing processes (Figures 2-26 and 2-27). The fuels, especially, are dominated by the glass/frit process group, representing 83% of the mass of all the fuels in the manufacturing life-cycle stage. It is LPG in this inventory that clearly dominates the fuel inputs at about 351 kg/functional unit (99% of the glass/frit fuel inputs) (Table 2-38). Water inputs are greatest in the fuel production processes, contributing 1,050 kg (or liter)/functional unit (Figure 2-28). Total energy use from manufacturing is shown in Figure 2-29. The glass/frit manufacturing process group contributes the greatest to the total energy impacts in the manufacturing stage. A sensitivity analysis will be conducted on the glass data and more details are provided in Section 2.7.3.

For outputs from the manufacturing stage, the mass of air emissions are dominated by fuel production (Figure 2-30). Individual material (pollutant) contributions for each process group are presented in Table 2-39. Wastewater outputs (i.e., the volume or mass of wastewater released) are also greatest from the fuel production processes (Figure 2-31; Table 2-40);

however, the mass of chemical pollutants in the wastewater is greatest from the glass/frit manufacturing process group (4.65 kg/functional unit) out of the total manufacturing stage mass of pollutants, which is 4.77 kg/functional unit (Figure 2-32; Table 2-40).

Hazardous wastes from the CRT manufacturing stage were a small portion of the overall hazardous wastes generated by mass. Nonetheless, for purposes of future manufacturing stage improvement assessments, Table 2-41 presents the individual material contributions for each manufacturing process group; and Figure 2-33 shows that fuels production contributes the most (0.62 kg/functional unit) hazardous waste to the manufacturing stage. Manufacturing solid wastes are not as small a portion of the total mass of solid wastes throughout the CRT life-cycle (42%) as hazardous wastes are, as was depicted in Figure 2-21. Fuels production is the greatest contributor to manufacturing-generated solid wastes (71.9 kg/functional unit), followed by PWB manufacturing (4.1 kg/functional unit) (Figure 2-34 and Table 2-43).

Radioactive waste and radioactivity are directly related to the electricity generation process and therefore, only the Japanese and U.S. electric grid processes generate these outputs (some small radioactivity outputs are generated by fuels production processes) in the manufacturing stage. (These outputs also occur in upstream processes that have an electric grid included in the inventory.) Tables 2-44 and 2-45 show that more radioactive wastes and radioactivity are from the Japanese grid. This is a result of more manuf acturing processes as modeled in this project being in Japan.

2.7.1.2 LCD inventory results

The LCD inventory is presented similar to the CRT inventory above. The total LCD inventory presented in Table 2-24 and Figures 2-5, 2-6, and 2-7 shows the inventory from all life-cycle stages combined. The totals by life-cycle stage are presented in Table 2-45, Figure 2-35, Figure 2-36, and Figure 2-37.

Table 2-45. LCD inventory by life-cycle stage

Inventory type	Upstream	Mfg	Use	EOL	Total	Units*
Inputs						
Primary materials	2.35e+02	4.92e+01	8.01e+01	-2.19e+00	3.62e+02	kg
Ancillary materials	1.06e+00	2.04e+02	1.29e+00	2.11e+00	2.08e+02	kg
Water	2.63e+02	2.15e+03	4.25e+02	-1.80e+01	2.82e+03	kg
Fuels	??	??	??	??	0.00e+00	kg (or L)
Electricity	3.46e+01	3.16e+02	8.53e+02	1.62e-01	1.20e+03	MJ
Total energy	6.33e+02	1.44e+03	8.53e+02	-8.44e+01	2.84e+03	MJ
Outputs						
Air pollutants	1.12e+02	6.48e+01	1.68e+02	1.30e+00	3.46e+02	kg
Wastewater	8.57e+00	3.12e+03	0	-2.41e+00	3.13e+03	kg
Water pollutants	4.60e-01	1.23e+00	2.62e-02	-4.09e-02	1.68e+00	kg (or L)
Hazardous waste	6.72e-03	4.64e+00	0	1.64e+00	6.29e+00	kg
Solid waste	1.31e+01	1.26e+01	3.11e+01	-4.42e+00	5.23e+01	kg
Radioactive waste	2.21e+01	3.14e+03	3.11e+01	-5.23e+00	3.19e+03	kg
Radioactivity	1.20e+07	1.02e+07	1.79e+07	3.40e+03	4.01e+07	Bq

*Per functional unit (i.e., one LCD monitor over its effective life)

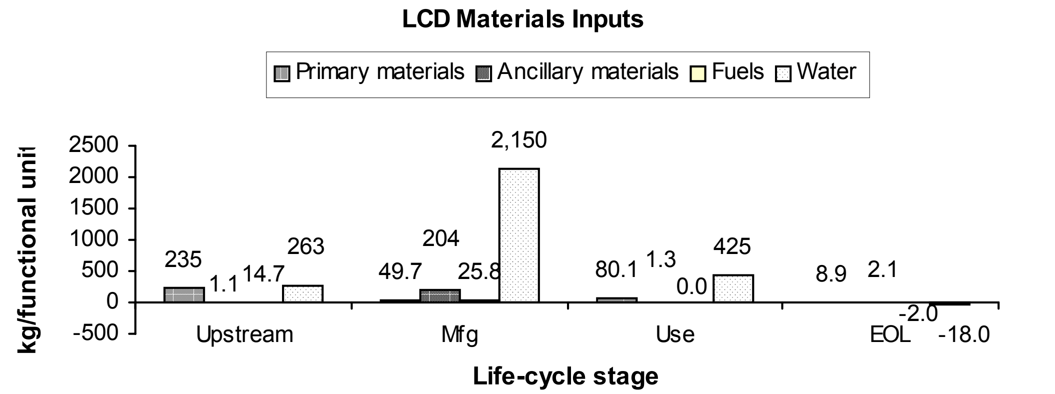

Figure 2-35. LCD mass-based material inputs by life-cycle stage

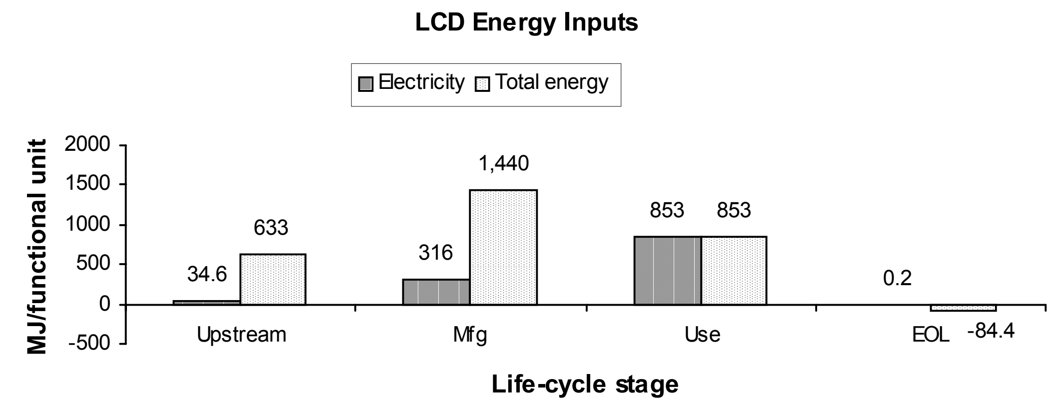

Figure 2-36. LCD energy-based inputs by life-cycle stage

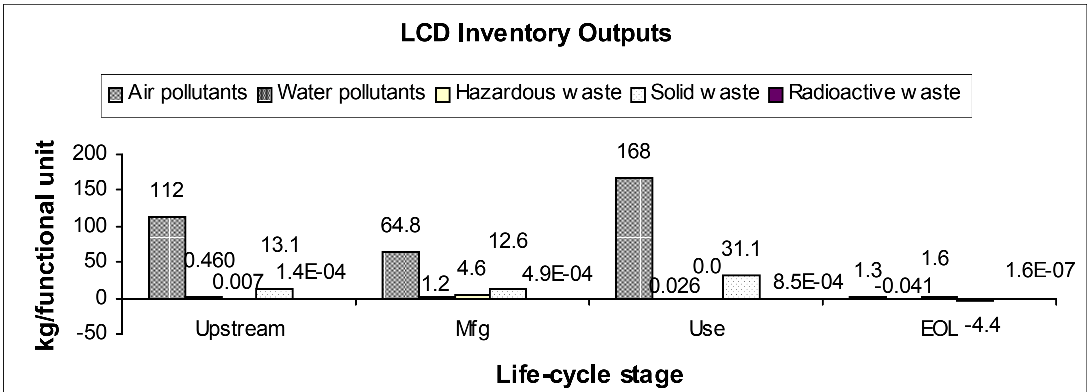

Figure 2-37. LCD mass-based material outputs by life-cycle stage

Considering inputs, Figure 2-35 shows that of the inputs measured in mass, the water inputs constitute the majority of the inputs by mass for the entire life cycle, and most of the water inputs are in the manufacturing life-cycle stage. Details on each inventory type are provided below. When considering which life-cycle stage contributes most to an inventory category, the manufacturing stage has the largest inventory by mass for ancillary materials, fuels, and water inputs. Primary material inputs are dominated by the upstream stages while electricity inputs are dominated by the use stage. The total energy is dominated by the manufacturing life-cycle stage (Figure 2-36). Note that LPG production from glass manufacturing does not dominate much of the LCD inventory as it did for the CRT because of the smaller amount of glass used in the LCD compared to the CRT.

Of the outputs measured in mass (air emissions, wastewater, water pollutants and hazardous, solid, and radioactive waste), wastewater constitutes the greatest output (Table 2-46); however, wastewater alone is not used to calculate impacts. Instead, water pollutants are used to calculate impacts and therefore listed separately in the inventory. Of the remaining outputs measured in mass (i.e., air emissions, water pollutants and hazardous, solid and radioactive waste), which are shown in Figure 2-37, air emissions are the greatest contributor to the outputs. Note again, as mentioned for the CRT, that radioactivity is measured in Bequerels (Bq) and cannot be compared on the same scale.

Considering each output type and their contributions by life-cycle stage, the mass of water pollutants is greatest in the manufacturing life-cycle stage, due to the fuel production processes that support fuel consumption in the manufacturing processes being included in the manufacturing life-cycle stage. Wastewater and hazardous waste outputs are greatest in the manufacturing stage; air emissions, solid waste, radioactive waste, and radioactivity have the greatest contribution from the use stage. As with the CRT, all the output totals represented in Table 2-45 include outputs to all dispositions.

The tables and figures discussed above show the total inventories for particular input or output types by life-cycle stage. Tables in Appendix J list each material that contributes to those totals. Figures 2-38 through 2-50 show the total contribution by life-cycle stage, based on the entire input/output type-specific tables in Appendix J. Summary tables for the LCD (Tables 2-46 through 2-54), developed from the Tables in Appendix J, show the top contributing inventory items to each input or output type. Note that Table 2-48 includes input/output types that are classified together as utilities: water, fuel, electricity and total energy.

LCD Primary Inputs

Figure 2-38 shows that most LCD primary materials by mass are from the upstream life-cycle stages. The top 99.9% of the materials contributing to the total LCD primary input inventory are shown in Table 2-46. The largest material contributors are natural gas, coal and petroleum (a combined 89% of all the primary LCD inputs), which are used to generate electricity consumed throughout the life-cycle of the monitor. Most of the electricity consumed in the LCD life-cycle is in the manufacturing and use stages, as was seen in Figure 2-36. However, most of the natural gas primary material reported in the materials processing stage (229 kg/functional unit) is not used to generate electricity, but is an ancillary material in the LCD monitor/module manufacturing process. More detail on the processes that contribute greatest within the manufacturing stage will be presented after brief discussions of the life-cycle stage breakdowns for each inventory type. For the complete list of primary materials in the LCD inventory, the total mass, and the mass contribution of each life-cycle stage, see Appendix J, Table J-10.

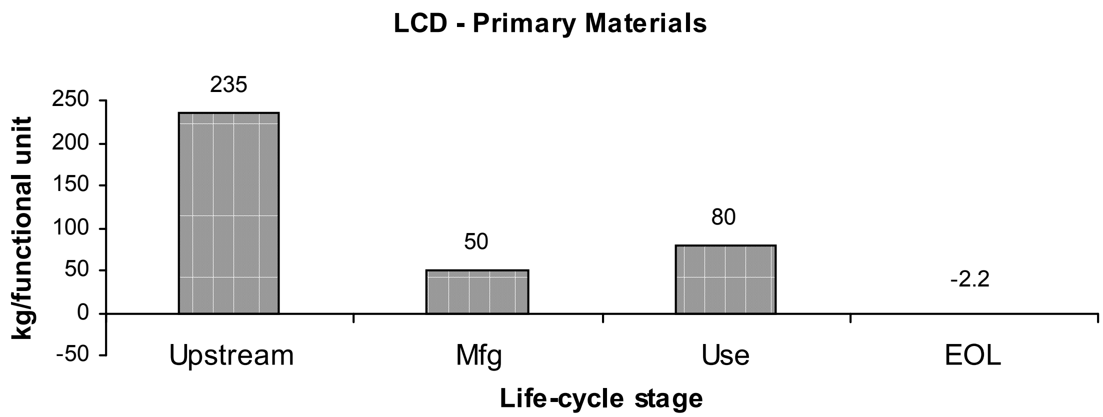

Figure 2-38. LCD primary material inputs by life-cycle stage

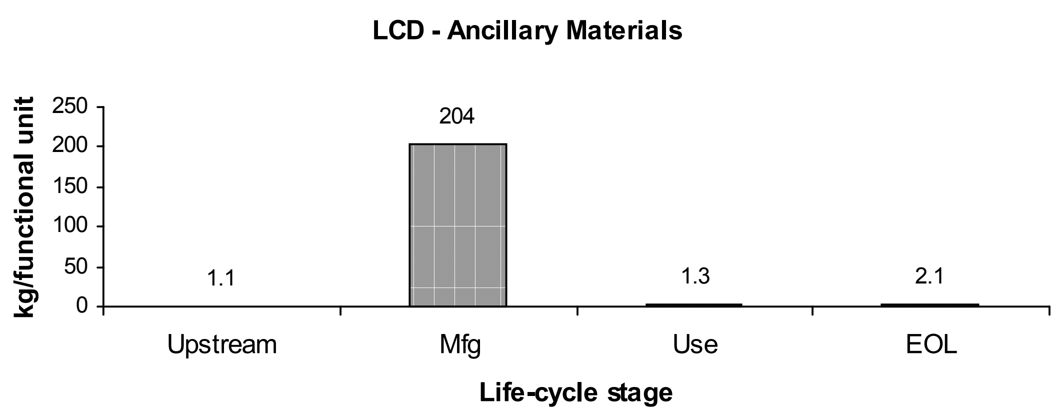

Figure 2-39. LCD ancillary material inputs by life-cycle stage

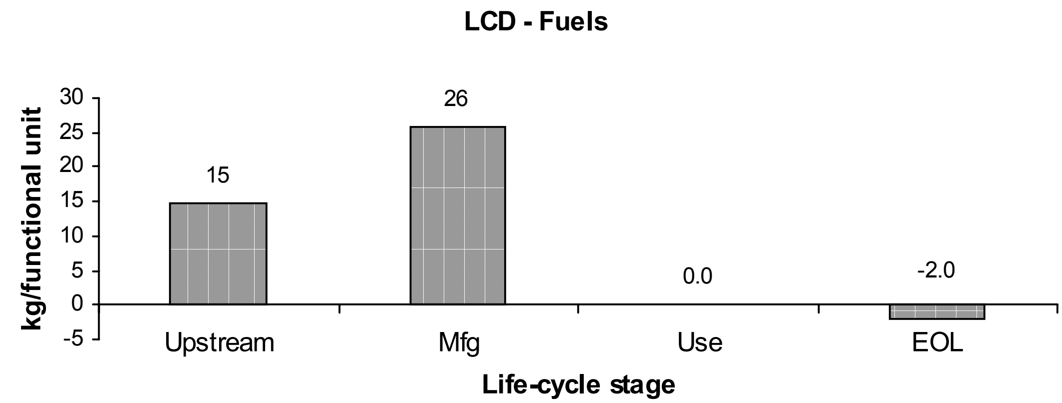

Figure 2-40. LCD fuel inputs by life-cycle stage

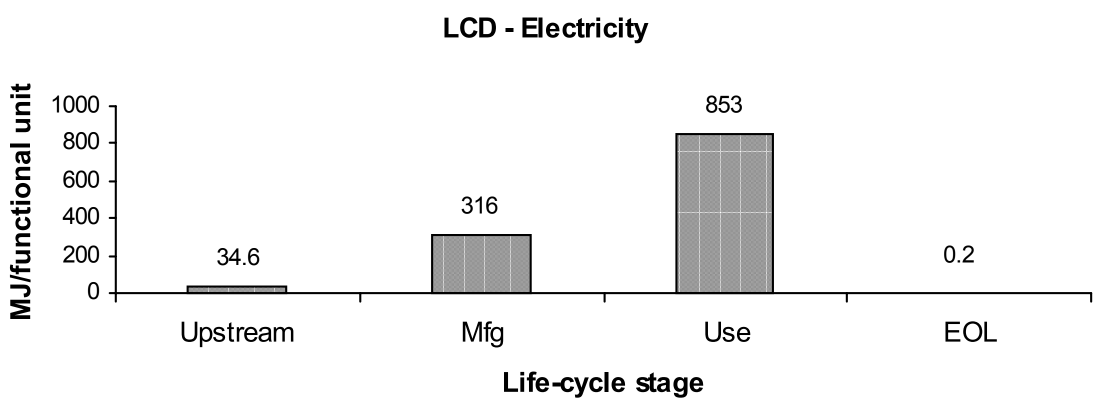

Figure 2-41. LCD electricity inputs by life-cycle stage

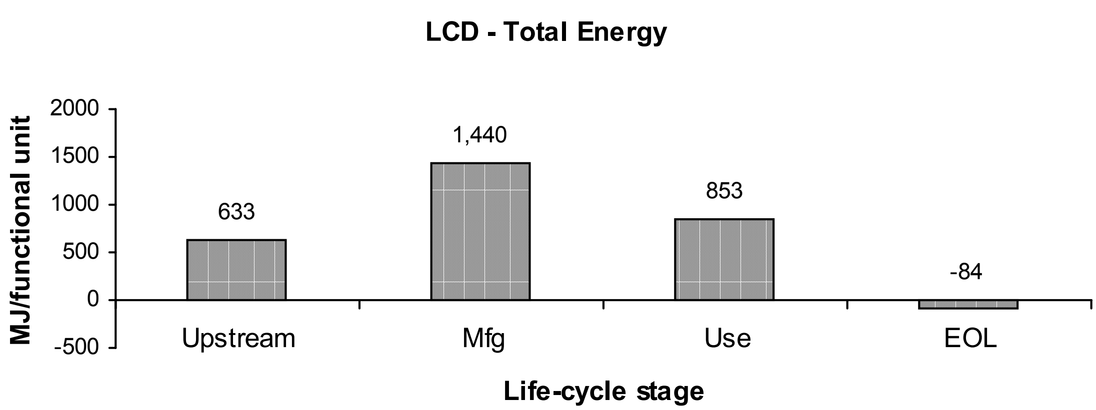

Figure 2-42. LCD energy inputs by life-cycle stage

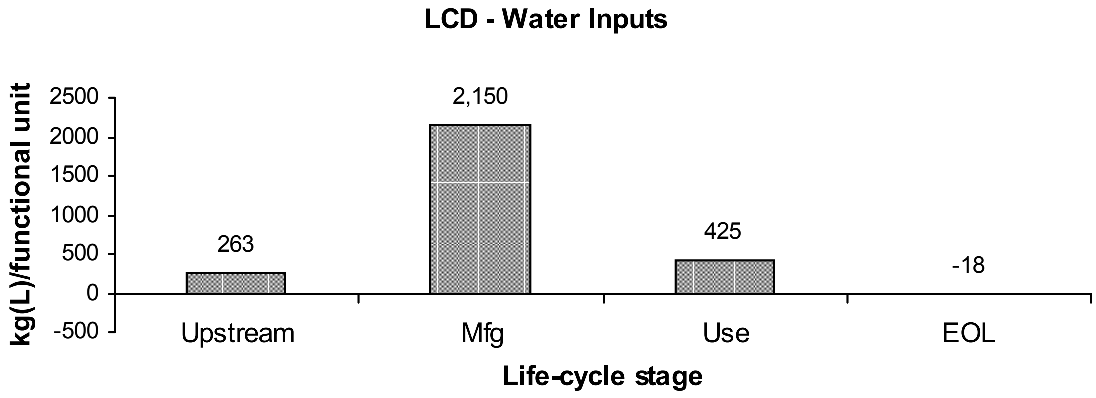

Figure 2-43. LCD water inputs by life-cycle stage

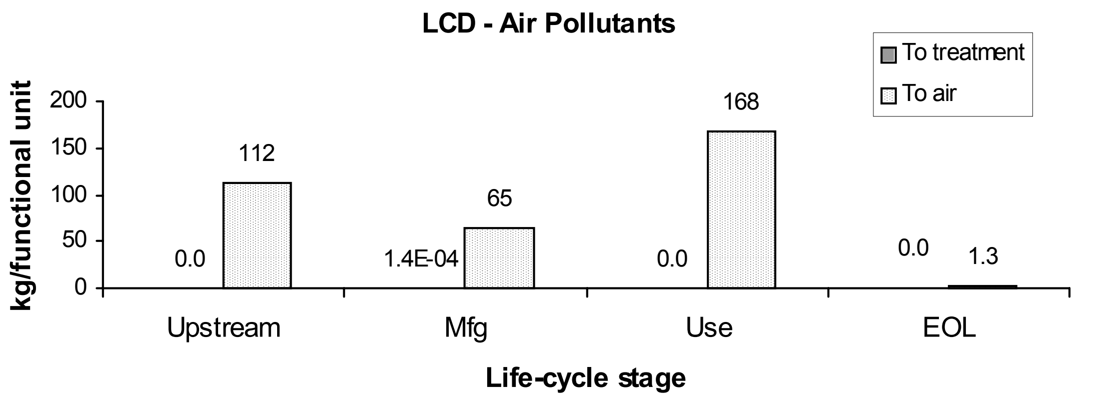

Figure 2-44. LCD air outputs by life-cycle stage

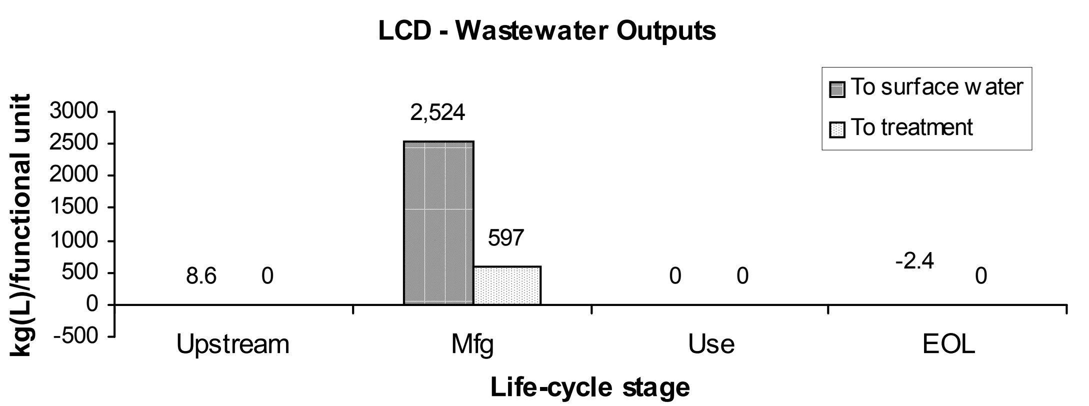

Figure 2-45. LCD wastewater outputs by life-cycle stage

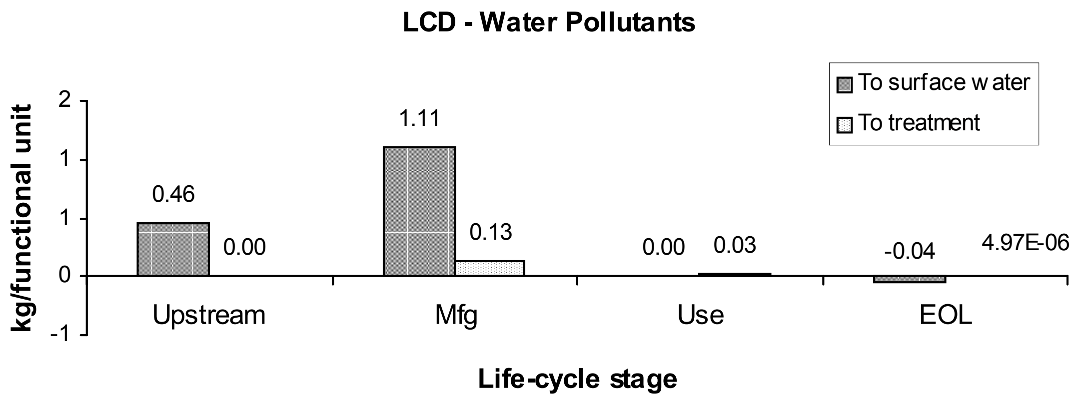

Figure 2-46. LCD water pollutant outputs by life-cycle stage

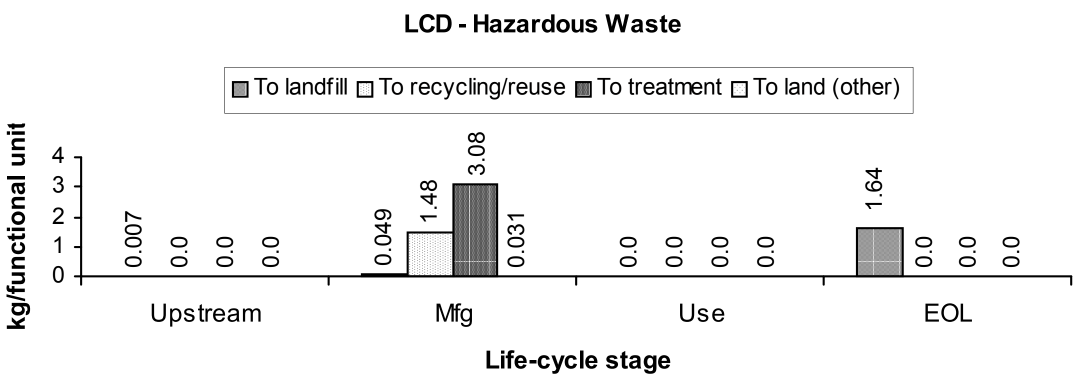

Figure 2-47. LCD hazardous waste outputs by life-cycle stage

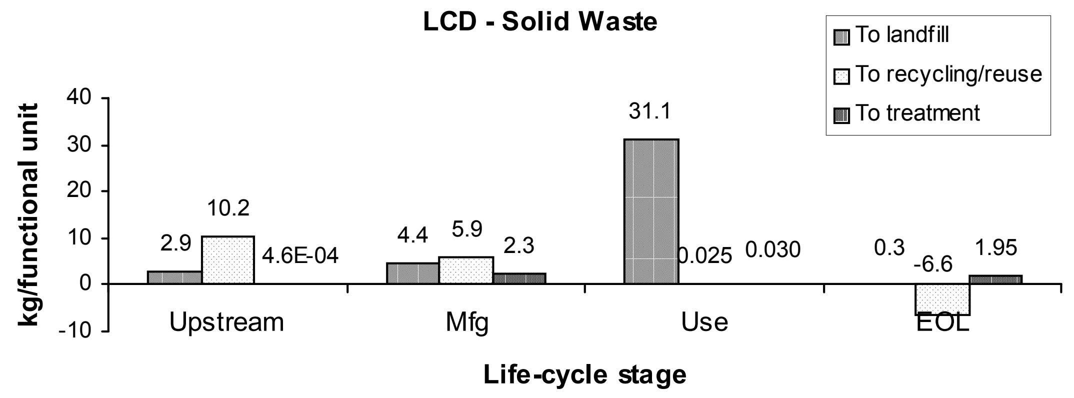

Figure 2-48. LCD solid waste outputs by life-cycle stage

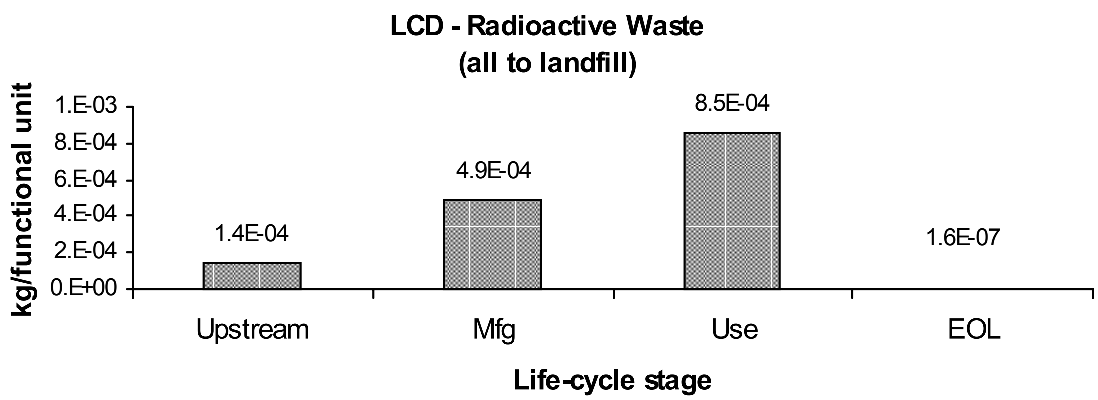

Figure 2-49. LCD radioactive waste outputs by life-cycle stage

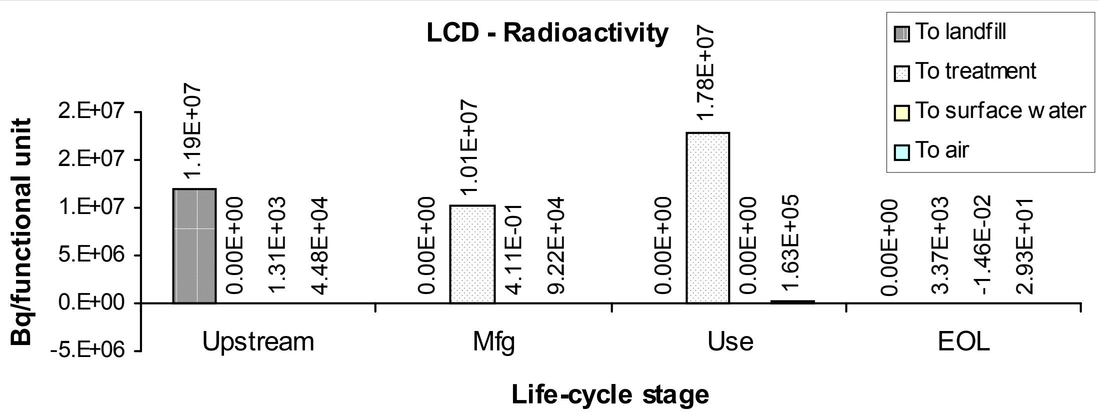

Figure 2-50. LCD radioactivity outputs by life-cycle stage

Table 2-46. Top 99.9% of LCD primary material inputs (kg/functional unit)

Material	Upstream	Mfg	Use	EOL	Total	% of total
Natural gas (in ground)	2.29E+02	5.16E+00	0	-1.08E+00	2.33E+02	64.25%
Coal, average (in ground)	1.72E+00	8.03E+00	6.69E+01	1.27E-02	7.67E+01	21.15%
Petroleum (in ground)	7.09E-01	2.23E+01	1.42E+00	-1.00E+00	2.34E+01	6.45%
Natural gas	0	4.22E+00	5.22E+00	-5.75E-02	9.39E+00	2.59%
Assembled LCD monitor	0	0	6.50E+00	0	6.50E+00	1.79%
Iron (Fe, ore)	3.26E+00	0	0	0	3.26E+00	0.90%
Steel	0	2.53E+00	0	0	2.53E+00	0.70%
Assembled 15" LCD backlight unit	0	1.48E+00	0	0	1.48E+00	0.41%
LCD module	0	1.18E+00	0	0	1.18E+00	0.33%
Polycarbonate resin	0	5.16E-01	0	0	5.16E-01	0.14%
Bauxite (Al2O3, ore)	0	5.09E-01	0	0	5.09E-01	0.14%
Iron scrap	4.63E-01	0	0	0	4.63E-01	0.13%
LCD glass	0	4.52E-01	0	0	4.52E-01	0.12%
Poly(methyl methacrylate)	0	3.83E-01	0	0	3.83E-01	0.11%
15" LCD light guide	0	3.74E-01	0	0	3.74E-01	0.10%
PWB-laminate	0	3.74E-01	0	0	3.74E-01	0.10%
Printed wiring board (PWB)	0	3.74E-01	0	0	3.74E-01	0.10%
Styrene-butadiene copolymers	0	3.62E-01	0	0	3.62E-01	0.10%
PPE	0	3.00E-01	0	0	3.00E-01	0.08%
Cables/wires	0	2.34E-01	0	0	2.34E-01	0.06%
LCD front glass (with color filters)	0	1.78E-01	0	0	1.78E-01	0.05%
Aluminum (elemental)	0	1.34E-01	0	0	1.34E-01	0.04%
Sand	0	1.11E-01	0	0	1.11E-01	0.03%
Recycled LCD glass	0	9.54E-02	0	0	9.54E-02	0.03%

LCD Ancillary Inputs

As presented in Figure 2-39, the greatest mass of ancillary LCD inputs is in the manufacturing life-cycle stage at approximately 204 kg/functional unit. Table 2-47 shows that liquified natural gas (LNG) contributes about 93% to this total. It is in the LCD module/monitor manufacturing process where this large amount of LNG was reported as an ancillary material (to be discussed below). Note that this is separate from LNG reported as a fuel, and LNG as an ancillary material is not used to calculate energy impacts in the LCIA. Following LNG is nitrogen at about 3% and clay at less than 1% of the total ancillary materials by mass. Excluding LNG from the inventory, nitrogen constitutes about 50% and clay 14% of the total ancillary materials in the LCD life-cycle. The contributions from the manufacturing stage will be discussed in further detail below. See Table J-11 in Appendix J for the complete list of ancillary materials in the LCD inventory.

Table 2-47. Top 99% of LCD ancillary material inputs (kg/functional unit)

Material	Upstream	Mfg	Use	EOL	Total	% of total
LNG	0	1.94e+02	0	0	1.94e+02	93.19%
Nitrogen	0	6.02e+00	0	0	6.02e+00	2.89%
Clay (in ground)	1.30e-03	0	0	1.69e+00	1.69e+00	0.81%
Limestone	0	1.08e-01	8.99e-01	1.71e-04	1.01e+00	0.48%
Sand (in ground)	9.55e-03	1.32e-03	0	5.60e-01	5.71e-01	0.27%
Sodium hydroxide	0	4.45e-01	0	0	4.45e-01	0.21%
Hydrogen	0	4.44e-01	0	0	4.44e-01	0.21%
Lime	0	4.74e-02	3.95e-01	7.49e-05	4.42e-01	0.21%
Sodium chloride (NaCl, in ground or sea)	4.37e-01	6.08e-04	0	1.08e-05	4.38e-01	0.21%
Limestone (CaCO3, in ground)	5.07e-01	5.49e-02	0	-1.55e-01	4.06e-01	0.20%
Isopropyl alcohol	0	3.49e-01	0	0	3.49e-01	0.17%
Sulfuric acid	0	3.25e-01	0	0	3.25e-01	0.16%

LCD Utility Inputs

Utility inputs in the LCD life-cycle are presented in Table 2-48 and include fuel (kg/functional unit), electricity (MJ/functional unit), water inputs (kg or L/functional unit), and total energy (MJ/functional unit; a combination of fuel and electricity inputs). Table 2-48 and Figure 2-40 show that most fuels (26 kg/functional unit) are used in the manufacturing stage. This represents 67% of the total fuels. LPG (16.8 kg/functional unit) dominates the total fuel inputs at 44% of all the fuels in the LCD life-cycle. More detail as to the breakdown by process within the manufacturing stage will be presented below after each input/output type is discussed.

Electricity inputs are dominated by the use stage (853 MJ/functional unit), followed by the manufacturing stage (316 MJ/functional unit) (see Figure 2-41). When fuel energy and electrical energy are combined into a total energy input value, the overall energy from manufacturing exceeds that from the use stage (1,440 MJ/functional unit versus 853 MJ/functional unit). This is also depicted in Figure 2-42.

The other utility considered in Table 2-48 is water (Figure 2-43). Approximately 76% (2,150 L/functional unit) of the water inputs in the LCD life-cycle are from the manufacturing processes. The life-cycle stage contributing the next most to water inputs is the use stage at 15% (425 L/functional unit). The upstream contributes about 9% (263 L/functional unit). Table J-12 in Appendix J provides the complete list of inventory items for the LCD.

Table 2-48. LCD utility inputs

Material	Upstream	Mfg	Use	EOL	Total	% of total
Fuels (kg/functional unit):						
LPG	0	1.68E+01	0	1.38E-03	1.68E+01	43.63%
Natural gas (in ground)	1.03E+01	2.41E+00	0	-1.38E-01	1.26E+01	32.66%
LNG	0	3.22E+00	0	0	3.22E+00	8.34%
Coal, average (in ground)	2.49E+00	6.86E-01	0	-7.66e-03	3.17E+00	8.21%
Petroleum (in ground)	1.52E+00	4.84E-01	0	-3.81e-02	1.96e+00	5.08%
Kerosene	0	4.65E-01	0	0	4.65e-01	1.21%
Coal, lignite (in ground)	4.10E-01	0	0	0	4.10e-01	1.06%
Natural gas	0	1.16E+00	0	-8.61E-01	3.01e-01	0.78%
Steam	0	1.45E-01	0	0	1.45e-01	0.37%
Fuel oil #6	0	1.25E-01	0	0	1.25e-01	0.33%
Fuel oil #2	0	5.42E-02	0	0	5.42e-02	0.14%
Uranium (U, ore)	7.86E-05	1.15E-05	0	0	9.01e-05	<0.01%
Fuel oil #4	0	2.11E-01	0	-9.09e-01	-6.99e-01	-1.81%
Total fuels	1.47E+01	2.58e+01	0	-1.95E+00	3.86e+01	100.00%
Electricity (MJ/functional unit):						
Electricity	3.46e+01	3.16e+02	8.53e+02	1.62e-01	1.20e+03	
Water (kg or L/functional unit):						
Water	2.63E+02	2.15E+03	4.25E+02	-1.80E+01	2.82e+03	
Total energy (fuels and electricity, MJ/functional unit):						
Energy	6.33E+02	1.44E+03	8.53E+02	-8.44E+01	2.84E+03	

LCD Air Outputs

Air emissions from the LCD life-cycle are greatest (by mass) in the use stage as seen in Figure 2-44. This indicates that most air emissions by mass are from the generation of electricity used by consumers of the monitors. Forty-nine percent of the total life-cycle air emissions by mass (or about 168 kg/functional unit) are from the use stage. Carbon dioxide (CO_2) emissions from the use stage alone constitute about 166 kg/functional unit, or almost 48% of all air emissions by mass in the life-cycle and nearly 99% of the use stage air emissions. The remaining air emissions that contribute to the top 99.99% of air emissions are presented in Table 2-49 and the complete list of air emissions are presented alphabetically in Table J-13 in Appendix J. The appendix also provides life-cycle stage subtotals. The next largest air emissions, by life-cycle stage, are emitted during the upstream stages, which contribute about 32% to the total life-cycle air emissions. All the air emissions in the inventory except for ethylacetate and methyl ethyl ketone from the manufacturing stage (a combined 1.36×10^{-4} kg/functional unit) were reported as being emitted directly to the air (see Appendix J, Table J-13). Only those materials directly released to the air are used to calculate impacts. This will be discussed further in Chapter 3.

Table 2-49. Top 99.99% of LCD air emissions (kg/functional unit)

Material	Disposition	Upstream	Mfg	Use	EOL	Total	% of total
Carbon dioxide	Air	1.07e+02	6.22e+01	1.66e+02	1.39e+00	3.36e+02	97.18%
Methane	Air	3.54e+00	1.22e-01	2.41e-01	-2.82e-02	3.87e+00	1.12%
Nitrogen oxides	Air	6.56e-01	7.62e-01	4.39e-01	-1.36e-02	1.84e+00	0.53%
Sulfur dioxide	Air	4.63e-02	2.95e-01	9.30e-01	2.96e-04	1.27e+00	0.37%
Tetramethyl ammonium	Air	0	6.43e-01	0	0	6.43e-01	0.19%
Other organics	Air	4.45e-01	1.35e-02	0	-2.41e-03	4.56e-01	0.13%
Carbon monoxide	Air	3.74e-01	3.85e-02	3.02e-02	-3.45e-03	4.39e-01	0.13%
Nitrogen fluoride	Air	0	2.45e-01	0	0	2.45e-01	0.07%
Nonmethane hydrocarbons	Air	2.07e-01	8.87e-03	0	-1.26e-03	2.15e-01	0.06%
Hydrochloric acid	Air	1.50e-03	6.58e-02	4.02e-02	-6.88e-04	1.07e-01	0.03%
Benzene	Air	8.85e-02	2.70e-03	4.36e-05	-4.82e-04	9.07e-02	0.03%
PM	Air	9.16e-02	6.99e-03	0	-1.24e-02	8.62e-02	0.02%
Ammonia	Air	1.12e-02	6.26e-02	0	-6.95e-05	7.37e-02	0.02%
Phosphine	Air	0	6.26e-02	0	0	6.26e-02	0.02%
Hydrofluoric acid	Air	2.27e-04	5.27e-02	5.02e-03	-1.47e-04	5.78e-02	0.02%
Sulfur oxides	Air	2.57e-02	4.07e-02	0	-1.93e-02	4.71e-02	0.01%
Unspecified LCD process	Air	0	4.49e-02	0	0	4.49e-02	0.01%
Cr-etchant, unspecified	Air	0	4.12e-02	0	0	4.12e-02	0.01%
Nitrogen dioxide	Air	3.08e-02	0	0	4.46e-04	3.12e-02	<0.01%
PM-10	Air	3.45e-07	6.85e-03	2.16e-02	3.43e-06	2.84e-02	<0.01%
Isopropyl alcohol	Air	0	1.78e-02	0	0	1.78e-02	<0.01%
Hydrocarbons, remaining	Air	9.30e-03	7.75e-03	0	-6.51e-04	1.64e-02	<0.01%
Al-etchant, unspecified	Air	0	1.37e-02	0	0	1.37e-02	<0.01%

LCD Water Outputs

The volume (or mass) of wastewater released throughout the LCD life-cycle is approximately 3,128 L (kg) per functional unit. Approximately 19% of that is sent to treatment as opposed to direct discharge to surface water (81%; Figure 2-45). The mass of chemical pollutants within the wastewater streams were calculated separately from the total wastewater volume. The total mass of water pollutants released, presented by life-cycle stage are shown in Figure 2-46. Of the small amount of water pollutants released, the manufacturing life-cycle stage contributes the greatest with approximately 1.23 kg per functional unit. This is about 73% of all the water pollutants for the entire life-cycle. The upstream stages have the second greatest mass of water pollutants at nearly 0.46 kg/functional unit (27%). The use and EOL stages are small contributors, with the EOL being negative due to recovery processes within the EOL stage. To see the top 99% contributors to the water pollutant quantities, Table 2-50 reveals that chloride and sodium ions contribute nearly 61% to all the water pollutants in the life-cycle, mostly from the manufacturing and upstream stages. For the complete inventory, listing water pollutants alphabetically and by life-cycle stage, see Appendix J, Table J-14. Further details on the manufacturing stage will be provided later.

Table 2-50. Top 99% of LCD water pollutant outputs (kg/functional unit)

Material	Disposition	Upstream	Mfg	Use	EOL	Total	% of total
Chloride ions	surface water	2.33e-01	3.12e-01	0	-1.58e-02	5.29e-01	31.53%
Sodium (+1)	surface water	1.73e-01	3.41e-01	0	-2.03e-02	4.94e-01	29.42%
Dissolved solids	surface water	3.21e-03	1.75e-01	0	-5.69e-05	1.78e-01	10.63%
COD	surface water	7.67e-03	8.20e-02	0	-2.69e-03	8.70e-02	5.18%
Nitrogen	surface water	1.44e-05	7.98e-02	0	0	7.98e-02	4.76%
Suspended solids	surface water	4.98e-03	5.80e-02	0	-1.44e-03	6.15e-02	3.66%
BOD	treatment	0	5.74e-02	0	0	5.74e-02	3.42%
COD	treatment	0	3.90e-02	0	0	3.90e-02	2.33%
BOD	surface water	7.72e-04	2.79e-02	0	-3.18e-04	2.83e-02	1.69%
Sulfate ion (-4)	surface water	2.40e-02	2.94e-03	0	-1.20e-06	2.69e-02	1.60%
Sulfate ion (-4)	treatment	0	1.32e-04	2.55e-02	4.84e-06	2.57e-02	1.53%
Fluorides (F-)	surface water	5.14e-05	1.29e-02	0	-5.01e-06	1.30e-02	0.77%
Nitrogen	treatment	0	1.26e-02	0	0	1.26e-02	0.75%
Phosphorus (yellow or white)	treatment	0	6.91e-03	0	0	6.91e-03	0.41%
Waste oil	surface water	1.75e-03	4.87e-03	0	-2.06e-04	6.41e-03	0.38%
Suspended solids	treatment	0	5.60e-03	6.65e-04	1.26e-07	6.26e-03	0.37%
Phosphorus (yellow or white)	surface water	1.92e-06	4.33e-03	0	0	4.33e-03	0.26%
Colon bacillus (bacteria in large intestine)	surface water	0	3.89e-03	0	0	3.89e-03	0.23%
Oil & grease	treatment	0	3.61e-03	0	0	3.61e-03	0.21%

LCD Hazardous Waste Outputs

The total mass of hazardous waste generated throughout the life-cycle of the LCD is about 6.29 kg/functional unit. Figure 2-47 shows that this is mostly from the manufacturing stage, which contributes 4.64 kg/functional unit, or almost 74%. The EOL stage hazardous waste outputs equal 1.64 kg/functional unit, or 26%. The disposition of the waste will be used to determine how impacts are calculated in Chapter 3. Only hazardous wastes sent to landfills are directly calculated as impacts, which will be presented and discussed in Chapter 3. Figure 2-47 shows what portion of hazardous wastes are landfilled, recycled/reused, treated or otherwise land-applied. Nearly all of the hazardous waste in the manufacturing stage (~99%) is recycled/reused or treated. Less than 1% of the hazardous waste from the manufacturing stage is landfilled. Nearly all the hazardous waste from the EOL stage is landfilled. Table 2-51 shows the top contributors to the LCD life-cycle. Note that multiple entries of a material are due to different dispositions for that material. See Table J-15 in Appendix J for the complete alphabetical inventory of hazardous waste outputs. Additional detail on the manufacturing stage are presented below.

Table 2-51. Top 99% of LCD hazardous waste outputs (kg/functional unit)

Material	Disposition	Upstream	Mfg	Use	EOL	Total	% of total
Isopropyl alcohol	treatment	0	1.91E+00	0	0	1.91E+00	30.41%
EOL LCD Monitor, landfilled	landfill	0	0	0	1.64E+00	1.64E+00	26.13%
Waste acid (mainly HF)	recycling/reuse	0	5.69E-01	0	0	5.69E-01	9.04%
Thinner, unspecified	treatment	0	5.40E-01	0	0	5.40E-01	8.57%
Remover, unspecified	treatment	0	3.03E-01	0	0	3.03E-01	4.81%
Sodium sulfate	recycling/reuse	0	2.44E-01	0	0	2.44E-01	3.89%
Isopropyl alcohol	recycling/reuse	0	1.69E-01	0	0	1.69E-01	2.69%
Tetramethyl ammonium hydroxide	recycling/reuse	0	1.42E-01	0	0	1.42E-01	2.26%
Waste acid (mainly HF)	treatment	0	1.36E-01	0	0	1.36E-01	2.15%
PWB-Waste cupric etchant	recycling/reuse	0	9.93E-02	0	0	9.93E-02	1.58%
Remover, unspecified	recycling/reuse	0	8.84E-02	0	0	8.84E-02	1.40%
Hazardous waste, unspecified	treatment	0	6.16E-02	0	0	6.16E-02	0.98%
Rinse, unspecified	recycling/reuse	0	4.67E-02	0	0	4.67E-02	0.74%
Spent solvent (non-halogenated)	treatment	0	4.66E-02	0	0	4.66E-02	0.74%
Hazardous waste, unspecified	landfill	6.72E-03	2.97E-02	0	-1.05E-03	3.54E-02	0.56%
Waste acids, unspecified	recycling/reuse	0	3.24E-02	0	0	3.24E-02	0.52%
Unspecified sludge	land (other than landfill)	0	3.09E-02	0	0	3.09E-02	0.49%
PWB-Solder dross	recycling/reuse	0	2.96E-02	0	0	2.96E-02	0.47%
Acetone	treatment	0	2.77E-02	0	0	2.77E-02	0.44%
Waste solvent (photoresist)	treatment	0	2.17E-02	0	0	2.17E-02	0.35%
Waste solvent (photoresist)	recycling/reuse	0	2.05E-02	0	0	2.05E-02	0.33%
Spent solvent (with halogenated materials)	treatment	0	1.55E-02	0	0	1.55E-02	0.25%
Phosphoric acid	landfill	0	1.44E-02	0	0	1.44E-02	0.23%

LCD Solid Waste Outputs

Figure 2-48 shows that the use stage contributes the most amount (31 kg/functional unit) of solid waste by mass to the LCD life-cycle, and 100% of that waste is landfilled. The manufacturing stage contributes 12.6 kg/functional unit. In terms of mass, the greatest material contributors to the solid waste outputs for the LCD life-cycle are coal waste (~41%), followed by dust/sludge (16%). Most of this is from the generation of electricity in the use stage (Table 2-52). Note also that the mass of an LCD monitor that is assumed to be landfilled (0.89 kg/functional unit) is 1.7% of the total mass of solid waste in the LCD life-cycle. See Appendix J, Table J-16 for the complete LCD solid waste inventory. The manufacturing stage breakdown will be discussed at the end of this section.

Table 2-52. Top 99% of LCD solid waste outputs (kg/functional unit)

Material	Disposition	Upstream	Mfg	Use	EOL	Total	% of total
Coal waste	landfill	0	2.28E+00	1.90E+01	3.60E-03	2.13E+01	40.64%
Dust/sludge	landfill	0	8.80E-01	7.34E+00	1.39E-03	8.23E+00	15.72%
Fly/bottom ash	landfill	0	5.70E-01	4.75E+00	9.01E-04	5.32E+00	10.16%
Unspecified solid waste	landfill	2.40E+00	0	0	-5.10E-01	1.89E+00	3.62%
Slag and ash	recycle/reuse	8.02E+00	3.40E+00	0	-9.67E+00	1.75E+00	3.35%
Unspecified solid waste	recycle/reuse	1.50E+00	2.11E-01	0	0	1.71E+00	3.27%
Unspecified solid waste	treatment	0	1.63E+00	0	0	1.63E+00	3.11%
Iron scrap	recycle/reuse	1.67E-01	0	0	1.10E+00	1.27E+00	2.42%
EOL LCD Monitor, incinerated	treatment	0	0	0	9.75E-01	9.75E-01	1.86%
EOL LCD Monitor, recycled	recycle/reuse	0	0	0	9.75E-01	9.75E-01	1.86%
EOL LCD Monitor, remanufactured	recycle/reuse	0	0	0	9.75E-01	9.75E-01	1.86%
EOL LCD Monitor, landfilled	landfill	0	0	0	8.94E-01	8.94E-01	1.71%
Unspecified sludge	recycle/reuse	0	8.46E-01	0	0	8.46E-01	1.62%
Waste LCD glass	recycle/reuse	0	7.20E-01	0	0	7.20E-01	1.38%
Unspecified waste	recycle/reuse	4.05E-01	1.72E-01	0	-9.83E-03	5.67E-01	1.08%
CARBON STEEL SCRAP	recycle/reuse	0	0	0	4.58E-01	4.58E-01	0.88%
Waste plastic from LCD modules	treatment	0	4.03E-01	0	0	4.03E-01	0.77%
Polycarbonate	recycle/reuse	0	0	0	3.90E-01	3.90E-01	0.75%
Waste alkali, unspecified	recycle/reuse	0	3.23E-01	0	0	3.23E-01	0.62%
Waste acid (containing F and detergents)	landfill	0	2.70E-01	0	0	2.70E-01	0.52%
Waste LCD glass	landfill	0	2.63E-01	0	0	2.63E-01	0.50%
Mineral waste	landfill	2.20E-01	1.26E-04	0	-4.46E-06	2.21E-01	0.42%
Mining waste	landfill	1.41E-01	0	0	-1.23E-06	1.41E-01	0.27%
Slag and ash	landfill	8.19E-02	3.49E-02	0	-1.99E-03	1.15E-01	0.22%
Waste acids, unspecified	treatment	0	1.05E-01	0	0	1.05E-01	0.20%
Mixed industrial (waste)	landfill	4.34E-02	4.83E-02	0	-1.35E-03	9.04E-02	0.17%
Waste alkali (color filter developer, unspecified)	recycle/reuse	0	8.91E-02	0	0	8.91E-02	0.17%

LCD Radioactive Waste Outputs

Radioactive waste outputs in the LCD inventory are limited to the electricity generation and steel production processes, with steel production processes accounting for only about 9% of the total. Therefore, radioactive wastes will be found wherever electricity is used in a process in the LCD life-cycle. Only very small amounts (approximately 0.0015 kg/functional unit) of radioactive waste are generated over the entire life-cycle of the LCD (Figure 2-49 and Table 2-53). As expected, the majority of this is linked to the use stage, where most electricity is used in the LCD life-cycle, followed by the manufacturing stage. Low-level radioactive waste (78%) and depleted uranium (21%) are most of the waste, with negligible amounts of highly radioactive waste and unspecified radioactive waste. The inventory of radioactive waste outputs is small, and therefore, Table 2-53 lists all material outputs associated with radioactive waste, in descending order of quantity. Table J-17 in Appendix J lists these in alphabetical order.

Table 2-53. LCD radioactive waste outputs (kg/functional unit)

Material	Disposition	Upstream	Mfg	Use	EOL	Total	% of total
Low-level radioactive waste	landfill	1.28E-04	3.74E-04	6.56E-04	1.24E-07	1.16E-03	78.49%
Uranium, depleted	landfill	0	1.12E-04	1.97E-04	3.73E-08	3.09E-04	20.93%
Radioactive waste (unspecified)	landfill	5.77E-06	0	0	0	5.77E-06	0.39%
Highly radioactive waste (Class C)	landfill	2.72E-06	0	0	0	2.72E-06	0.18%
Total radioactive wastes		1.37E-04	4.87E-04	8.52E-04	1.62E-07	1.48E-03	100.00%

LCD Radioactivity Outputs

Radioactivity is also inventoried in this project as isotopes that are released to the environment. Radioactivity is measured in Bequerels and may be released to air, water, or land, or may also be treated. The quantity of radioactivity for each life-cycle stage and different dispositions are presented in Figure 2-50. Table 2-54 shows the top contributors to the total radioactivity outputs. Radioactivity outputs are associated with the generation of electricity and, therefore, the greatest quantity of radioactivity is from the use stage. Appendix J, Table J-18 lists the complete inventory.

Table 2-54. Top 99.9% of LCD radioactivity outputs (Bq/functional unit)

Material	Disposition	Upstream	Mfg.	Use	EOL	Total	% of total
Molybdenum-99 (isotope)	treatment	0	1.01e+07	1.76e+07	3.35e+03	2.77e+07	69.09%
Plutonium-241 (isotope)	landfill	1.18e+07	0	0	0	1.18e+07	29.33%
Tritium-3 (isotope)	treatment	0	5.96e+04	1.04e+05	1.98e+01	1.64e+05	0.41%
Xenon-133 (isotope)	air	7.63e+02	4.98e+03	1.16e+05	2.21e+01	1.22e+05	0.30%
Xenon-133M (isotope)	air	0	6.59e+04	7.73e+03	1.47e+00	7.36e+04	0.18%
Plutonium-240 (isotope)	landfill	5.08e+04	0	0	0	5.08e+04	0.13%
Cesium-135 (isotope)	landfill	4.59e+04	0	0	0	4.59e+04	0.11%
Radon-222 (isotope)	air	4.30e+04	0	0	0	4.30e+04	0.11%
Plutonium-239 (isotope)	landfill	3.57e+04	0	0	0	3.57e+04	0.09%
Xenon-133 (isotope)	treatment	0	9.43e+03	1.65e+04	3.13e+00	2.60e+04	0.06%
Tritium-3 (isotope)	air	1.09e+02	7.98e+03	1.40e+04	2.65e+00	2.21e+04	0.05%
Krypton-85 (isotope)	air	5.45e+01	5.64e+03	9.88e+03	1.88e+00	1.56e+04	0.04%

LCD Manufacturing Stage

The inventory tables that show the specific materials in each inventory (i.e., those in Appendix J and Tables 2-46 through 2-54) are the sums of the materials from one or more processes within a life-cycle stage. To burrow down deeper into the data, the manufacturing stage inventory data are broken down by process or group of processes. Similar to the CRT analysis, groups of processes were combined where fewer than three companies provided data for a process or where confidentiality agreements precluded presenting individual process data (Table 2-55). Burrowing further into the contributing processes or process groups is necessary for future manufacturing improvement assessments.

Table 2-55. LCD process groups

Process group	Process(es) included
Monitor/module	panel/module manufacturing, monitor assembly
Panel components	polarizer manufacturing, patterning color filters on glass, liquid crystal manufacturing
LCD glass	LCD glass manufacturing
Backlight	backlight unit assembly, backlight light guide, cold cathode fluorescent lamp manufacturing
PWB	PWB manufacturing
Japanese grid	electricity generation - Japanese electric grid
U.S. grid	electricity generation - U.S. electric grid
Fuels	production of fuel oils #2, #4 and #6, LPG, and natural gas

Tables 2-56 through 2-64 list the specific inventories for each process group in the manufacturing stage for each input and output type. Figures 2-51 through 2-61 graph the total inventories for each process group for each input and output type. As revealed in Table 2-45, ancillary material inputs, fuels, water and total energy inputs all were greatest in the manufacturing stage. Similarly, wastewater, water pollutant and hazardous waste outputs were also greatest in the manufacturing stage. Similar to the discussion for CRTs, the manufacturing stage inventories by process group, for all input and output types, are presented here to reveal more specifics about the inventory and to allow manufacturers to conduct improvement assessments.

Table 2-56. LCD manufacturing stage primary material inputs

Material	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process Group			
Module/Monitor			
1,4-butanolide	4.06e-04	0.01%	
1-methyl-2-pyrrolidinone	4.06e-04	0.04%	
2-(2-butoxyethoxy)-ethanol acetate	8.08e-06	<0.01%	
AlNd	2.97e-05	<0.01%	
Aluminum (elemental)	1.01e-01	1.34%	
Assembled 15" LCD backlight unit	1.48e+00	19.67%	
Cables/wires	2.30e-01	3.07%	
Glycol ethers	4.06e-04	0.01%	
Indium tin oxide	5.26e-04	0.01%	
LCD front glass (with color filters)	1.78e-01	2.38%	
LCD glass	2.16e-01	2.88%	
LCD material (confidential)	3.11e-04	<0.01%	
LCD module	1.18e+00	15.78%	
LCD spacers, unspecified	1.69e-05	<0.01%	
Liquid crystals, for 15" LCD	1.24e-03	0.02%	
Mild fiber	7.34e-07	<0.01%	
Molybdenum	1.78e-04	<0.01%	
MoW	9.09e-04	0.01%	
Polarizer	4.07e-02	0.54%	
Polycarbonate resin	4.01e-01	5.35%	
Polyimide alignment layer, unspecified	4.86e-04	0.01%	
PPE	3.00e-01	4.00%	
Printed wiring board (PWB)	3.74e-01	4.98%	
Solder (60% tin, 40% lead)	3.81e-02	0.51%	
Steel	2.50e+00	33.38%	
Styrene-butadiene copolymers	3.62e-01	4.82%	
Titanium	1.33e-04	<0.01%	
Triallyl isocyanurate	1.54e-05	<0.01%	
Triphenyl phosphate	9.25e-02	1.23%	
Unspecified LCD material	1.19e-04	<0.01%	
Total	**7.50e+00**	100.00%	**15.26%**
Panel Components			
3,4,5-trifluorobromobenzene	2.64e-04	0.08%	
3,4-difluorobromobenzene	3.65e-04	0.04%	
4-4(-propylcyclohexyl)cyclohexanone	2.18e-04	0.07%	
4-bromophenol	3.27e-04	0.10%	
4-ethylphenol	7.00e-05	0.02%	
4-pentylphenol	3.42e-04	0.11%	
4-propionylphenol	1.94e-04	0.06%	
LCD glass	2.36e-01	74.75%	
Pigment color resist, unspecified	3.72e-02	11.80%	

Table 2-56. LCD manufacturing stage primary material inputs

Material	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process Group			
Polyester adhesive	6.25e-04	0.20%	
Polyethylene terephthalate	3.14e-02	9.96%	
Polyvinyl alcohol	8.61e-03	2.73%	
Total	**3.16e-01**	100.00%	**0.64%**
Glass mfg			
Barium Carbonate	1.37e-02	4.90%	
Glass, unspecified	2.28e-03	0.23%	
Potassium Carbonate	1.75e-02	6.24%	
Recycled LCD glass	9.54e-02	34.00%	
Sand	1.11e-01	39.64%	
Sodium Carbonate	2.26e-02	8.05%	
Strontium Carbonate	1.53e-02	5.47%	
Zircon Sand	2.51e-03	0.90%	
Total	**2.81e-01**	99.42%	**0.57%**
Backlight			
15" LCD light guide	3.74e-01	37.18%	
Aluminum (elemental)	3.35e-02	3.35%	
Argon	3.53e-05	<0.01%	
Backlight lamp (CCFL)	1.94e-03	0.19%	
Cables/wires	3.43e-03	0.34%	
Glass, unspecified	4.14e-02	4.11%	
Mercury	3.99e-06	<0.01%	
Metals, remaining unspeciated	6.81e-04	0.07%	
Neon	6.31e-05	0.01%	
Poly(methyl methacrylate)	3.83e-01	38.12%	
Polycarbonate resin	1.14e-01	11.38%	
Polyethylene terephthalate	2.74e-02	2.72%	
Rubber, unspecified	6.01e-04	0.06%	
Steel	2.52e-02	2.50%	
Total	**1.01e+00**	100.04%	**2.04%**
PWB			
PWB-laminate	3.74e-01	94.35%	
Solder (63% tin; 37% lead)	2.24e-02	5.66%	
Total	**3.96e-01**	100.00%	**0.81%**
Japanese Grid			
Coal, average (in ground)	7.69e+00	47.41%	
Natural gas	4.20e+00	25.89%	
Petroleum (in ground)	4.33e+00	26.69%	
Uranium, yellowcake	1.02e-03	0.01%	
Total	**1.62e+01**	100.00%	**32.96%**
U.S. Grid			
Coal, average (in ground)	3.47e-01	90.97%	

Table 2-56. LCD manufacturing stage primary material inputs

Material	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process Group			
Natural gas	2.71e-02	7.10%	
Petroleum (in ground)	7.36e-03	1.93%	
Uranium, yellowcake	9.39e-06	<0.01%	
Total	**3.82e-01**	100.01%	**0.78%**
Fuel Production			
Natural gas (in ground)	5.16e+00	22.33%	
Petroleum (in ground)	1.79e+01	77.67%	
Total	**2.31e+01**	100.00%	**46.94%**
Grand Total	**4.92e+01**		**100.00%**

Table 2-57. LCD manufacturing stage ancillary material inputs

Material	Quantity(kg/ functional unit)	% of process group total	% of grand total
Process Group			
Module/Monitor			
1,4-butanolide	4.04e-05	6.91%	
1-Methoxy-2-propanol	1.10e-02	100.00%	
2-(2-butoxyethoxy)-ethanol	3.04e-02	0.02%	
2,2,4-trimethylpentane	1.52e-05	<0.01%	
2-ethoxyl ethylacetate	1.78e-03	<0.01%	
Acetic acid	6.40e-03	<0.01%	
Acetone	1.03e-02	0.01%	
Al-etchant, unspecified	5.88e-03	<0.01%	
Aluminum sulfate	1.05e-01	0.05%	
Ammonia	1.55e-02	0.01%	
Ammonium bifluoride	2.36e-03	<0.01%	
Ammonium fluoride	1.14e-02	0.01%	
Ammonium hydroxide	5.15e-06	<0.01%	
Argon	7.87e-03	<0.01%	
Calcium hydroxide	1.39e-01	0.07%	
Carbon dioxide	3.74e-05	<0.01%	
Chlorine	1.55e-02	0.01%	
Cleaner, unspecified	1.47e-04	<0.01%	
Cresol-formaldehyde resin	8.29e-04	<0.01%	
Cr-etchant, unspecified	1.77e-02	0.01%	
Cyclohexane	2.03e-05	<0.01%	
Dimethylsulfoxide	6.63e-02	0.03%	
Ethanol	1.35e-02	0.01%	
Ethanol amine	7.85e-02	0.04%	
Ferric chloride	8.92e-03	<0.01%	
Fluorocarbon resin	3.38e-06	<0.01%	
Flux, unspecified	7.35e-05	<0.01%	
Glycol ethers	2.12e-02	0.01%	
Helium	6.18e-04	<0.01%	
Hexamethyldisilizane	2.58e-04	<0.01%	
Hydrochloric acid	4.31e-02	0.02%	
Hydrofluoric acid	4.21e-02	0.02%	
Hydrogen	4.44e-01	0.22%	
Hydrogen peroxide	1.47e-04	<0.01%	
Isopropyl alcohol	3.49e-01	0.17%	
ITO etchant, unspecified	2.94e-03	<0.01%	
Krypton	2.58e-05	<0.01%	
LNG	1.94e+02	95.80%	
Methyl ethyl ketone	7.35e-06	<0.01%	
Monosilane	1.12e-03	<0.01%	
N-Butylacetate	3.83e-02	0.02%	

Table 2-57. LCD manufacturing stage ancillary material inputs

Material	Quantity(kg/ functional unit)	% of process group total	% of grand total
Process Group			
Nitric acid	1.24e-02	0.01%	
Nitrogen	5.90e+00	2.91%	
Nitrogen fluoride	1.08e-01	0.05%	
Nitrous oxide	1.36e-03	<0.01%	
Oxygen	7.75e-03	<0.01%	
Perfluoromethane	1.29e-03	<0.01%	
Phosphine	2.69e-02	0.01%	
Phosphoric acid	3.95e-02	0.02%	
Photoresist, unspecified	1.38e-02	0.01%	
Polyaluminum chloride	6.40e-03	<0.01%	
Polyethylene mono(nonylphenyl) ether glycol	3.40e-04	<0.01%	
Polyimide, unspecified	2.94e-05	<0.01%	
Propylene glycol	4.46e-03	<0.01%	
Propylene glycol monomethyl ether acetate	1.56e-02	0.01%	
Rinse, unspecified	5.27e-02	0.03%	
Sodium dihydrogen phosphate dihydrate	4.06e-06	<0.01%	
Sodium hydroxide	3.59e-01	0.18%	
Solder, unspecified	7.35e-05	<0.01%	
Sulfur hexafluoride	1.62e-02	0.01%	
Sulfuric acid	2.29e-01	0.11%	
Surfactant, unspecified	1.09e-04	<0.01%	
Synthetic resin, unspecified	6.57e-04	<0.01%	
Tetramethyl ammonium hydroxide	1.29e-01	0.06%	
Unspecified LCD process material	2.58e-02	0.01%	
Water	6.88e-02	0.03%	
Xylene (mixed isomers)	1.57e-03	<0.01%	
Total	**2.03e+02**	**206.91%**	**99.48%**
Panel Components			
Acetone	1.03e-02	3.19%	
Borax	9.13e-05	0.01%	
Carbon dioxide	4.82e-03	1.50%	
Cyclohexane	3.89e-03	1.21%	
Developing solution, unspecified	4.00e-02	12.45%	
Diluent, unspecified	8.27e-03	2.57%	
Ethanol	1.17e-02	3.65%	
Ethylacetate	9.68e-04	0.30%	
Exfoliation liquid, unspecified	1.43e-02	4.44%	
HCFC-225ca	1.37e-04	0.04%	
HCFC-225cb	1.37e-04	0.04%	
Heptane	1.03e-02	3.19%	
Hydrochloric acid	1.74e-03	0.54%	
Hydrogen	3.14e-06	<0.01%	

Table 2-57. LCD manufacturing stage ancillary material inputs

Material	Quantity(kg/ functional unit)	% of process group total	% of grand total
Process Group			
Methyl ethyl ketone	4.84e-04	0.15%	
Nitric acid second cerium ammonium	1.13e-02	3.51%	
Nitrogen	1.17e-01	36.27%	
Orthoboric acid	7.30e-04	0.23%	
Perchloric acid	3.82e-03	1.19%	
Photoresist, unspecified	2.94e-03	0.91%	
Polyethylene terephthalate	3.20e-02	9.93%	
Sulfuric acid	1.58e-02	4.91%	
Tetrahydrofuran	3.82e-03	1.19%	
Toluene	2.75e-02	8.56%	
Total	**3.22e-01**	99.99%	**0.16%**
LCD Glass			
Aluminum Oxide	1.56e-03	17.30%	
Cerium Oxide	1.52e-04	1.68%	
Chromium Oxide	2.60e-06	0.03%	
Hydrofluoric acid	3.66e-03	40.61%	
Pumice	3.64e-03	40.37%	
Total	**9.02e-03**	100.00%	**0.00%**
Backlight			
Diethyl ether	9.28e-05	14.78%	
Ethanol	4.63e-05	7.36%	
Process material for backlight assembly	7.03e-05	11.19%	
Unspecified ancillary material	4.19e-04	66.67%	
Total	**6.28e-04**	100.00%	**0.00%**
PWB			
Ammonium chloride	3.42e-02	6.68%	
Ammonium hydroxide	3.42e-02	3.42%	
Formaldehyde	2.91e-03	0.57%	
Glycol ethers	1.04e-02	2.03%	
Hydrochloric acid	8.46e-02	16.51%	
Hydrogen peroxide	1.37e-02	2.67%	
Nitric acid	5.99e-02	11.70%	
Polyethylene glycol	2.23e-02	4.34%	
Potassium hydroxide	1.88e-02	3.68%	
Potassium permanganate	5.14e-04	0.10%	
Potassium peroxymonosulfate	3.12e-02	6.08%	
PWB-solder mask solids	1.93e-02	3.76%	
Sodium Carbonate	1.42e-02	2.77%	
Sodium hydroxide	8.56e-02	16.71%	
Sulfuric acid	8.05e-02	15.72%	
Total	**5.12e-01**	96.74%	**0.25%**
Japanese Grid			

Table 2-57. LCD manufacturing stage ancillary material inputs

Material	Quantity(kg/ functional unit)	% of process group total	% of grand total
Process Group			
Lime	4.53e-02	30.57%	
Limestone	1.03e-01	69.43%	
Total	**1.48e-01**	100.00%	**0.07%**
U.S. Grid			
Lime	2.05e-03	30.52%	
Limestone	4.66e-03	69.48%	
Total	**6.71e-03**	100.00%	**0.00%**
Fuel Production			
Bauxite (Al2O3, ore)	2.16e-03	3.66%	
Limestone (CaCO3, in ground)	5.49e-02	93.07%	
Sand (in ground)	1.32e-03	2.24%	
Sodium chloride (NaCl, in ground or in sea)	6.08e-04	1.03%	
Total	**5.90e-02**	100.00%	**0.03%**
Grand Total	**2.04e+02**		**100.00%**

Table 2-58. LCD manufacturing stage utility inputs

Material	Quantity	% of process group total	% of grand total
Process group			
Fuels (kg/functional unit):			
Monitor/Module			
Fuel oil #4	2.11e-01	4.09%	
Kerosene	2.98e-01	5.77%	
LNG	3.22e+00	62.40%	
Liquified petroleum gas (LPG)	5.83e-01	11.30%	
Natural gas	8.48e-01	16.44%	
Total	**5.16e+00**	95.91%	**20.13%**
Panel Components			
Kerosene	1.68e-01	31.97%	
Natural gas	1.18e-07	<0.01%	
Steam (100 psig)	1.45e-01	27.56%	
Fuel oil #2	4.07e-04	0.08%	
Fuel oil #6	1.25e-01	23.91%	
Natural gas	8.64e-02	16.47%	
Total	**5.25e-01**	68.03%	**2.05%**
LCD glass			
Fuel oil #2	5.38e-02	0.33%	
Liquified petroleum gas (LPG)	1.62e+01	99.33%	
Natural gas	5.63e-02	0.34%	
Total	**1.64e+01**	100.00%	**63.87%**
Backlight			
LNG	4.17e-06	50.00%	
Natural gas	4.17e-06	50.00%	
Total	**8.33e-06**	200.00%	**0.00%**
PWB			
Natural gas	**??**		**ERR**
Fuels			
Coal, average (in ground)	6.86e-01	19.19%	
Natural gas (in ground)	2.41e+00	67.27%	
Petroleum (in ground)	4.84e-01	13.54%	
Uranium (U, ore)	1.15e-05	<0.01%	
Total	**3.58e+00**	100.00%	**13.96%**
Grand Total	**2.56e+01**		**100.00%**
Electricity (MJ/functional unit):			
Monitor/Module	2.59e+02		**81.80%**
Panel Components	4.64e+01		**14.70%**
LCD glass	2.20e+00		**0.70%**
Backlight	4.46e+00		**1.41%**
PWB	4.43e+00		**1.40%**
Total	**3.16e+02**		**100.00%**

Table 2-58. LCD manufacturing stage utility inputs

Material	Quantity	% of process group total	% of grand total
Process group			
Water (kg or L/functional unit):			
Monitor/Module	1.08e+03		**49.96%**
Panel Components	2.08e+02		**9.66%**
LCD glass	1.62e+00		**0.08%**
Backlight	1.92e+02		**8.91%**
PWB	1.86e+01		**0.86%**
Japanese electric grid	1.49e+02		**6.91%**
U.S. electric grid	2.20e+00		**0.10%**
Fuels	5.07e+02		**23.53%**
Total	**2.15e+03**		**100.00%**
Total energy (fuels and electricity, MJ/functional unit):			
Monitor/Module	5.08e+02		**35.36%**
Panel Components	6.29e+01		**4.38%**
LCD glass	7.05e+02		**49.03%**
Backlight	4.46e+00		**0.31%**
PWB	1.21e+01		**0.84%**
Fuels	1.45e+02		**10.09%**
Total	**1.44e+03**		**100.00%**

Table 2-59. LCD manufacturing stage air outputs

Material	**Quantity (kg/ functional unit)**	**% of process group total**	**% of grand total**
Process Group			
Module/Monitor			
Acetic acid	1.36e-03	0.07%	
Acetone	1.86e-04	0.02%	
Al-etchant, unspecified	1.37e-02	0.75%	
Ammonia	6.23e-02	3.41%	
Argon	5.80e-03	0.32%	
Carbon dioxide	2.16e-03	0.12%	
Cr-etchant, unspecified	4.12e-02	2.25%	
Cyclohexane	4.85e-05	<0.01%	
Diethylene glycol	9.69e-05	0.01%	
Hexamethyldisilizane	1.37e-06	<0.01%	
Hydrochloric acid	6.06e-02	3.31%	
Hydrofluoric acid	5.21e-02	2.85%	
Hydrogen	1.33e-04	0.01%	
Isopropyl alcohol	1.78e-02	0.97%	
ITO etchant, unspecified	6.86e-03	0.38%	
Monosilane	1.54e-03	0.08%	
N-bromoacetamide	9.18e-03	0.50%	
Nitric acid	2.69e-04	0.01%	
Nitrogen fluoride	2.45e-01	13.43%	
Nitrogen oxides	5.48e-01	30.00%	
Phosphine	6.26e-02	3.43%	
Phosphoric acid	4.85e-05	<0.01%	
PM	1.10e-05	<0.01%	
Polyimide, unspecified	1.40e-04	0.01%	
Sulfur hexafluoride	7.30e-03	0.40%	
Sulfur oxides	1.12e-03	0.06%	
Tetramethyl ammonium hydroxide	6.43e-01	35.16%	
Unspecified LCD process material	4.49e-02	2.46%	
Total	**1.83e+00**	100.00%	**2.82%**
Panel Components			
Carbon dioxide	4.82e-03	81.79%	
Ethylacetate	2.44e-06	<0.01%	
HCFC-225ca	1.40e-04	2.37%	
HCFC-225cb	1.40e-04	2.37%	
Heptane	7.77e-05	1.32%	
Hydrochloric acid	7.32e-06	0.12%	
Methyl ethyl ketone	1.35e-04	2.29%	
Nitrogen oxides	4.11e-04	6.98%	
Nonmethane hydrocarbons, remaining unspeciated	7.77e-05	1.32%	
PM	2.74e-05	0.47%	
Toluene	5.44e-05	0.92%	

Table 2-59. LCD manufacturing stage air outputs

Material	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process Group			
Total	**5.89e-03**	100.00%	**0.01%**
LCD Glass			
Carbon dioxide	1.30e-01	98.45%	
Carbon monoxide	2.07e-07	<0.01%	
Chromium	6.40e-09	<0.01%	
Nitrogen oxides	2.04e-03	1.55%	
PM	5.06e-06	<0.01%	
Sulfur oxides	2.36e-06	<0.01%	
Total	**1.32e-01**	100.03%	**0.20%**
Backlight			
Diethyl ether	9.26e-05	0.31%	
Ethanol	4.63e-05	0.16%	
Nitrogen oxides	2.95e-02	99.29%	
Process material for backlight assembly	7.03e-05	0.24%	
Total	**2.97e-02**	100.00%	**0.05%**
PWB			
Formaldehyde	**1.71e-05**		**0.00%**
Japanese Grid			
1,1,1-Trichloroethane	2.17e-07	<0.01%	
1,2-Dichloroethane	1.54e-07	<0.01%	
2,3,7,8-TCDD	5.65e-14	<0.01%	
2,3,7,8-TCDF	1.96e-13	<0.01%	
2,4-Dinitrotoluene	1.07e-09	<0.01%	
2-Chloroacetophenone	2.69e-08	<0.01%	
2-Methylnaphthalene	8.00e-10	<0.01%	
5-Methyl chrysene	8.46e-11	<0.01%	
Acenaphthene	1.45e-08	<0.01%	
Acenaphthylene	1.11e-09	<0.01%	
Acetaldehyde	2.19e-06	<0.01%	
Acetophenone	5.77e-08	<0.01%	
Acrolein	1.11e-06	<0.01%	
Anthracene	1.53e-09	<0.01%	
Antimony	3.20e-06	<0.01%	
Arsenic	2.36e-06	<0.01%	
Barium	1.74e-06	<0.01%	
Benzene	5.13e-06	<0.01%	
Benzo[a]anthracene	2.69e-09	<0.01%	
Benzo[a]pyrene	1.46e-10	<0.01%	
Benzo[b,j,k]fluoranthene	1.31e-09	<0.01%	
Benzo[g,h,i]perylene	1.45e-09	<0.01%	
Benzyl chloride	2.69e-06	<0.01%	
Beryllium	1.09e-07	<0.01%	

Table 2-59. LCD manufacturing stage air outputs

Material	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process Group			
Biphenyl	6.53e-09	<0.01%	
Bromoform	1.50e-07	<0.01%	
Bromomethane	6.15e-07	<0.01%	
Cadmium	4.74e-07	<0.01%	
Carbon dioxide	5.18e+01	99.14%	
Carbon disulfide	5.00e-07	<0.01%	
Carbon monoxide	9.43e-03	0.02%	
Chloride ions	2.07e-04	<0.01%	
Chlorobenzene	8.46e-08	<0.01%	
Chloroform	2.27e-07	<0.01%	
Chromium (III)	1.86e-06	<0.01%	
Chromium (VI)	4.51e-07	<0.01%	
Chrysene	1.80e-09	<0.01%	
Cobalt	3.98e-06	<0.01%	
Copper	1.07e-06	<0.01%	
Cumene hydroperoxide	2.04e-08	<0.01%	
Cyanide (-1)	9.61e-06	<0.01%	
Di(2-ethylhexyl)phthalate	2.81e-07	<0.01%	
Dibenzo[a,h]anthracene	9.95e-10	<0.01%	
Dichloromethane	1.11e-06	<0.01%	
Dimethyl sulfate	1.85e-07	<0.01%	
Dioxins, remaining unspeciated	2.51e-12	<0.01%	
Ethyl Chloride	1.61e-07	<0.01%	
Ethylbenzene	3.99e-07	<0.01%	
Ethylene dibromide	4.61e-09	<0.01%	
Fluoranthene	5.88e-09	<0.01%	
Fluorene	6.15e-09	<0.01%	
Fluorides (F-)	2.22e-05	<0.01%	
Formaldehyde	3.43e-05	<0.01%	
Furans, remaining unspeciated	4.00e-12	<0.01%	
Hexane	2.58e-07	<0.01%	
Hydrochloric acid	4.61e-03	0.01%	
Hydrofluoric acid	5.77e-04	<0.01%	
Indeno(1,2,3-cd)pyrene	1.51e-09	<0.01%	
Isophorone	2.23e-06	<0.01%	
Lead (Pb, ore)	1.48e-06	<0.01%	
Magnesium	4.23e-05	<0.01%	
Manganese (Mn, ore)	3.67e-06	<0.01%	
Mercury	3.97e-07	<0.01%	
Methane	2.73e-04	<0.01%	
Methyl chloride	2.04e-06	<0.01%	

Table 2-59. LCD manufacturing stage air outputs

Material	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process Group			
Methyl ethyl ketone	1.50e-06	<0.01%	
Methyl hydrazine	6.54e-07	<0.01%	
Methyl methacrylate	7.69e-08	<0.01%	
Methyl tert-butyl ether	1.34e-07	<0.01%	
Molybdenum	5.20e-07	<0.01%	
Naphthalene	7.44e-07	<0.01%	
Nickel	4.95e-05	<0.01%	
Nitrogen oxides	1.37e-01	0.26%	
Nitrous oxide	3.76e-04	<0.01%	
o-xylene	6.49e-08	<0.01%	
Phenanthrene	1.75e-08	<0.01%	
Phenol	6.15e-08	<0.01%	
PM-10	6.72e-03	0.01%	
Propionaldehyde	1.46e-06	<0.01%	
Pyrene	4.24e-09	<0.01%	
Selenium	5.40e-06	<0.01%	
Styrene	9.61e-08	<0.01%	
Sulfur dioxide	2.90e-01	0.56%	
Tetrachloroethylene	1.65e-07	<0.01%	
TOCs, remaining unspeciated	6.63e-04	<0.01%	
Toluene	4.81e-06	<0.01%	
Vanadium	1.92e-05	<0.01%	
Vinyl acetate	2.92e-08	<0.01%	
Xylene (mixed isomers)	1.42e-07	<0.01%	
Zinc (elemental)	1.73e-05	<0.01%	
Total	**5.22e+01**	100.84%	**80.58%**
U.S. Grid			
1,1,1-Trichloroethane	3.71e-09	<0.01%	
1,2-Dichloroethane	6.95e-09	<0.01%	
2,3,7,8-TCDD	2.48e-15	<0.01%	
2,3,7,8-TCDF	8.86e-15	<0.01%	
2,4-Dinitrotoluene	4.86e-11	<0.01%	
2-Chloroacetophenone	1.22e-09	<0.01%	
2-Methylnaphthalene	5.16e-12	<0.01%	
5-Methyl chrysene	3.82e-12	<0.01%	
Acenaphthene	1.10e-10	<0.01%	
Acenaphthylene	4.37e-11	<0.01%	
Acetaldehyde	9.90e-08	<0.01%	
Acetophenone	2.60e-09	<0.01%	

Table 2-59. LCD manufacturing stage air outputs

Material	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process Group			
Acrolein	5.04e-08	<0.01%	
Anthracene	3.77e-11	<0.01%	
Antimony	8.45e-09	<0.01%	
Arsenic	7.26e-08	<0.01%	
Barium	3.98e-09	<0.01%	
Benzene	2.26e-07	<0.01%	
Benzo[a]anthracene	1.80e-11	<0.01%	
Benzo[a]pyrene	6.60e-12	<0.01%	
Benzo[b,j,k]fluoranthene	2.06e-11	<0.01%	
Benzo[g,h,i]perylene	6.98e-12	<0.01%	
Benzyl chloride	1.22e-07	<0.01%	
Beryllium	3.69e-09	<0.01%	
Biphenyl	2.95e-10	<0.01%	
Bromoform	6.77e-09	<0.01%	
Bromomethane	2.78e-08	<0.01%	
Cadmium	9.33e-09	<0.01%	
Carbon dioxide	8.61e-01	98.98%	
Carbon disulfide	2.26e-08	<0.01%	
Carbon monoxide	1.57e-04	0.02%	
Chloride ions	3.52e-07	<0.01%	
Chlorobenzene	3.82e-09	<0.01%	
Chloroform	1.02e-08	<0.01%	
Chromium (III)	4.71e-08	<0.01%	
Chromium (VI)	1.40e-08	<0.01%	
Chrysene	1.98e-11	<0.01%	
Cobalt	2.35e-08	<0.01%	
Copper	1.93e-09	<0.01%	
Cumene	9.20e-10	<0.01%	
Cyanide (-1)	4.34e-07	<0.01%	
Di(2-ethylhexyl)phthalate	1.27e-08	<0.01%	
Dibenzo[a,h]anthracene	1.69e-12	<0.01%	
Dichloromethane	5.04e-08	<0.01%	
Dimethyl sulfate	8.33e-09	<0.01%	
Dioxins, remaining unspeciated	1.13e-13	<0.01%	
Ethyl Chloride	7.29e-09	<0.01%	
Ethylbenzene	1.64e-08	<0.01%	
Ethylene dibromide	2.08e-10	<0.01%	
Fluoranthene	1.30e-10	<0.01%	
Fluorene	1.63e-10	<0.01%	

Table 2-59. LCD manufacturing stage air outputs

Material	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process Group			
Fluoride	3.78e-08	<0.01%	
Formaldehyde	1.64e-07	<0.01%	
Furans, remaining unspeciated	1.80e-13	<0.01%	
Hexane	1.16e-08	<0.01%	
Hydrochloric acid	2.08e-04	0.02%	
Hydrofluoric acid	2.60e-05	<0.01%	
Indeno(1,2,3-cd)pyrene	1.28e-11	<0.01%	
Isophorone	1.01e-07	<0.01%	
Lead	2.47e-08	<0.01%	
Magnesium	1.91e-06	<0.01%	
Manganese	8.83e-08	<0.01%	
Mercury	1.45e-08	<0.01%	
Methane	1.25e-03	0.14%	
Methyl chloride	9.20e-08	<0.01%	
Methyl ethyl ketone	6.77e-08	<0.01%	
Methyl hydrazine	2.95e-08	<0.01%	
Methyl methacrylate	3.47e-09	<0.01%	
Methyl tert-butyl ether	6.08e-09	<0.01%	
Molybdenum	1.13e-09	<0.01%	
Naphthalene	3.54e-09	<0.01%	
Nickel	1.33e-07	<0.01%	
Nitrogen oxides	2.28e-03	0.26%	
Nitrous oxide	6.58e-06	<0.01%	
o-xylene	1.10e-10	<0.01%	
Phenanthrene	4.85e-10	<0.01%	
Phenol	2.78e-09	<0.01%	
Phosphorus (yellow or white)	9.59e-09	<0.01%	
PM-10	1.12e-04	0.01%	
Propionaldehyde	6.60e-08	<0.01%	
Pyrene	6.45e-11	<0.01%	
Selenium	2.26e-07	<0.01%	
Styrene	4.34e-09	<0.01%	
Sulfur dioxide	4.83e-03	0.56%	
Tetrachloroethylene	7.47e-09	<0.01%	
TOCs, remaining unspeciated	1.12e-05	<0.01%	
Toluene	4.92e-08	<0.01%	
Vanadium	3.41e-08	<0.01%	
Vinyl acetate	1.32e-09	<0.01%	
Xylene (mixed isomers)	6.42e-09	<0.01%	

Table 2-59. LCD manufacturing stage air outputs

Material	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process Group			
Zinc (elemental)	2.95e-08	<0.01%	
Total	**8.70e-01**	100.83%	**1.34%**
Fuel Production			
1,1,1-Trichloroethane	6.91e-09	<0.01%	
1,2-Dichloroethane	1.38e-08	<0.01%	
1,4-Dichlorobenzene	1.89e-08	<0.01%	
2,4-Dinitrotoluene	9.68e-11	<0.01%	
2-Chloroacetophenone	2.42e-09	<0.01%	
3-Methylcholanthrene	2.84e-11	<0.01%	
5-Methyl chrysene	7.60e-12	<0.01%	
Acenaphthene	2.77e-10	<0.01%	
Acenaphthylene	1.16e-10	<0.01%	
Acetaldehyde	1.97e-07	<0.01%	
Acetophenone	5.18e-09	<0.01%	
Acrolein	1.00e-07	<0.01%	
Aldehydes	8.98e-05	<0.01%	
Aluminum (elemental)	9.59e-07	<0.01%	
Ammonia	3.53e-04	<0.01%	
Anthracene	1.15e-10	<0.01%	
Antimony	1.15e-10	<0.01%	
Aromatic hydrocarbons	2.55e-09	<0.01%	
Arsenic	7.13e-07	<0.01%	
Barium	1.77e-08	<0.01%	
Benzene	2.70e-03	0.03%	
Benzo[a]anthracene	6.97e-11	<0.01%	
Benzo[a]pyrene	3.84e-11	<0.01%	
Benzo[b,j,k]fluoranthene	3.80e-11	<0.01%	
Benzo[b]fluoranthene	3.09e-11	<0.01%	
Benzo[g,h,i]perylene	3.21e-11	<0.01%	
Benzo[k]fluoranthene	3.09e-11	<0.01%	
Benzyl chloride	2.42e-07	<0.01%	
Beryllium	7.31e-08	<0.01%	
Biphenyl	5.88e-10	<0.01%	
Bromoform	1.35e-08	<0.01%	
Bromomethane	5.53e-08	<0.01%	
Butane	3.31e-05	<0.01%	
Cadmium	4.18e-08	<0.01%	
Calcium	8.31e-07	<0.01%	
Carbon dioxide	9.44e+00	97.19%	

Table 2-59. LCD manufacturing stage air outputs

Material	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process Group			
Carbon disulfide	4.49e-08	<0.01%	
Carbon monoxide	2.89e-02	0.30%	
Chloride ions	1.75e-06	<0.01%	
Chlorine	1.01e-09	<0.01%	
Chlorobenzene	7.60e-09	<0.01%	
Chloroform	2.04e-08	<0.01%	
Chromium (III)	1.05e-06	<0.01%	
Chromium (VI)	1.05e-06	<0.01%	
Chrysene	6.70e-11	<0.01%	
Cobalt	1.27e-07	<0.01%	
Copper	7.98e-08	<0.01%	
Cumene	1.83e-09	<0.01%	
Cyanide (-1)	8.64e-07	<0.01%	
Di(2-ethylhexyl)phthalate	2.52e-08	<0.01%	
Dibenzo[a,h]anthracene	2.18e-11	<0.01%	
Dichloromethane	1.00e-07	<0.01%	
Dimethyl sulfate	1.66e-08	<0.01%	
Dimethylbenzanthracene	2.36e-10	<0.01%	
Dioxins, remaining unspeciated	5.60e-12	<0.01%	
Ethane	4.88e-05	<0.01%	
Ethyl Chloride	1.45e-08	<0.01%	
Ethylbenzene	3.28e-08	<0.01%	
Ethylene dibromide	4.15e-10	<0.01%	
Fluoranthene	3.01e-10	<0.01%	
Fluorene	3.66e-10	<0.01%	
Fluorides (F-)	1.98e-07	<0.01%	
Formaldehyde	5.78e-05	<0.01%	
Furans, remaining unspeciated	2.60e-11	<0.01%	
Halogenated hydrocarbons (unspecified)	1.42e-14	<0.01%	
HALON-1301	2.47e-11	<0.01%	
Hexane	2.84e-05	<0.01%	
Hydrocarbons, remaining unspeciated	7.75e-03	0.08%	
Hydrochloric acid	4.15e-04	<0.01%	
Hydrofluoric acid	5.18e-05	<0.01%	
Hydrogen sulfide	1.51e-04	<0.01%	
Indeno(1,2,3-cd)pyrene	5.31e-11	<0.01%	
Iron	1.85e-06	<0.01%	
Isophorone	2.00e-07	<0.01%	
Lead	6.39e-07	<0.01%	

Table 2-59. LCD manufacturing stage air outputs

Material	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process Group			
Magnesium	3.80e-06	<0.01%	
Manganese	1.15e-06	<0.01%	
Mercury	4.55e-08	<0.01%	
Metals, remaining unspeciated	1.60e-08	<0.01%	
Methane	1.20e-01	1.24%	
Methyl chloride	1.83e-07	<0.01%	
Methyl ethyl ketone	1.35e-07	<0.01%	
Methyl hydrazine	5.88e-08	<0.01%	
Methyl methacrylate	6.91e-09	<0.01%	
Methyl tert-butyl ether	1.21e-08	<0.01%	
Molybdenum	9.92e-08	<0.01%	
Naphthalene	1.98e-08	<0.01%	
Nickel	6.06e-06	<0.01%	
Nitrogen oxides	4.27e-02	0.44%	
Nitrous oxide	8.13e-04	0.01%	
Nonmethane hydrocarbons, remaining unspeciated	8.79e-03	0.09%	
n-Propane	8.67e-08	<0.01%	
Other organics	1.35e-02	0.14%	
o-xylene	1.59e-07	<0.01%	
Pentane	4.10e-05	<0.01%	
Phenanthrene	1.22e-09	<0.01%	
Phenol	5.53e-09	<0.01%	
Phosphorus (yellow or white)	6.10e-07	<0.01%	
PM	6.95e-03	0.07%	
PM-10	1.11e-05	<0.01%	
Polycyclic aromatic hydrocarbons	2.84e-12	<0.01%	
Propionaldehyde	1.31e-07	<0.01%	
Pyrene	2.00e-10	<0.01%	
Selenium	4.81e-07	<0.01%	
Silicon	8.31e-07	<0.01%	
Sodium	4.92e-06	<0.01%	
Styrene	8.64e-09	<0.01%	
Sulfur oxides	3.96e-02	0.41%	
Tetrachloroethylene	1.49e-08	<0.01%	
Toluene	2.63e-07	<0.01%	
Vanadium	1.30e-05	<0.01%	
Vinyl acetate	2.63e-09	<0.01%	
Zinc (elemental)	6.04e-07	<0.01%	
Total	**9.72e+00**	101.01%	**15.00%**

Table 2-59. LCD manufacturing stage air outputs

Material	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process Group			
Grand Total	6.48e+01		100.00%

Table 2-60. LCD manufacturing stage water outputs

Material	Disposition	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process Group				
WASTEWATER STREAMS				
Module/monitor	both	2.87e+03		**91.80%**
Panel components	both	3.53e-01		**0.01%**
LCD glass	surface water	1.67e+00		**0.05%**
Backlight	both	1.92e+02		**6.15%**
PWB	treatment	1.86e+01		**0.60%**
Fuels	surface water	4.33e+01		**1.39%**
Total		**3.12e+03**		**100.00%**
WATER POLLUTANTS				
Module/monitor				
1,1,1-Trichloroethane	surface water	2.29e-08	<0.01%	
Antimony	surface water	1.14e-07	<0.01%	
Arsenic	surface water	1.14e-07	<0.01%	
BOD	surface water	1.74e-02	6.69%	
BOD	treatment	5.05e-02	19.41%	
Boron	surface water	4.58e-06	<0.01%	
Cadmium	surface water	1.14e-07	<0.01%	
Chromium	surface water	8.84e-06	<0.01%	
Chromium (VI)	surface water	2.29e-07	<0.01%	
COD	surface water	2.68e-03	1.03%	
COD	treatment	3.90e-02	14.99%	
Colon bacillus (bacteria in large intestine)	surface water	3.89e-03	1.50%	
Copper	surface water	9.18e-07	<0.01%	
Cyanide (-1)	surface water	3.66e-06	<0.01%	
Cyanide (-1)	treatment	6.67e-07	<0.01%	
Dissolved solids	surface water	7.55e-03	2.90%	
Fluorides (F-)	surface water	1.28e-02	4.91%	
Fluorides (F-)	treatment	2.40e-04	0.09%	
Hexane	surface water	5.88e-04	0.23%	
Iron	surface water	2.63e-06	<0.01%	
Lead	surface water	6.17e-06	<0.01%	
Manganese	surface water	2.29e-07	<0.01%	
Mercury	surface water	9.69e-08	<0.01%	
Nickel	surface water	2.29e-07	<0.01%	
Nitrogen	surface water	7.93e-02	30.45%	
Nitrogen	treatment	1.16e-02	4.45%	
Oil & grease	surface water	2.02e-04	0.08%	
Oil & grease	treatment	3.53e-03	1.35%	
Organic phosphorus, unspecified	surface water	2.29e-07	<0.01%	
Phenol	surface water	2.29e-07	<0.01%	
Phosphorus (yellow or white)	surface water	4.31e-03	1.65%	
Phosphorus (yellow or white)	treatment	6.91e-03	2.65%	

Table 2-60. LCD manufacturing stage water outputs

Material	Disposition	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process Group				
Polychlorinated biphenyls	surface water	1.14e-08	<0.01%	
Suspended solids	surface water	1.55e-02	5.96%	
Suspended solids	treatment	4.26e-03	1.64%	
Tetrachloroethylene	surface water	2.29e-08	<0.01%	
Tin	surface water	4.58e-07	<0.01%	
Trichloroethylene	surface water	2.29e-08	<0.01%	
Zinc (elemental)	surface water	2.63e-06	<0.01%	
Total		**2.60e-01**	100.21%	**21.11%**
Panel components				
BOD	surface water	1.34e-03	15.44%	
BOD	treatment	3.89e-03	44.73%	
Borax	treatment	1.31e-06	0.02%	
COD	surface water	2.21e-03	25.45%	
Hydrochloric acid	treatment	3.29e-06	0.04%	
Nitrogen	surface water	5.71e-04	6.58%	
Orthoboric acid	treatment	1.31e-06	0.02%	
Phosphorus (yellow or white)	surface water	2.48e-05	0.29%	
Suspended solids	surface water	6.46e-04	7.43%	
Total		**8.69e-03**	100.00%	**0.70%**
LCD glass				
BOD	surface water	3.80e-07	<0.01%	
Chloride ions	surface water	4.68e-02	21.73%	
Chromium	surface water	3.80e-09	<0.01%	
COD	surface water	3.80e-07	<0.01%	
Dissolved solids	surface water	1.68e-01	77.84%	
Fluorides (F-)	surface water	1.36e-04	0.06%	
Iron	surface water	1.28e-04	0.06%	
Lead	surface water	2.01e-06	<0.01%	
Nickel	surface water	3.80e-09	<0.01%	
Nitrate	surface water	1.83e-07	<0.01%	
Oil & grease	surface water	3.34e-04	0.16%	
Suspended solids	surface water	3.35e-04	0.16%	
Total		**2.15e-01**	100.00%	**17.46%**
Backlight				
BOD	treatment	3.00e-03	54.50%	
Iron	treatment	8.33e-05	1.51%	
Lead	treatment	8.33e-07	0.02%	
Mercury	treatment	8.33e-08	<0.01%	
Nickel	treatment	3.33e-06	0.06%	
Nitrogen	treatment	1.00e-03	18.17%	
Oil & grease	treatment	8.33e-05	1.51%	
Suspended solids	treatment	1.33e-03	24.22%	

Table 2-60. LCD manufacturing stage water outputs

Material	Disposition	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process Group				
Total		**5.50e-03**	100.00%	**0.45%**
PWB				
Copper (+1 & +2)	treatment	4.28e-05	85.71%	
Lead cmpds	treatment	7.14e-06	14.29%	
Total		**5.00e-05**	100.00%	**0.00%**
Japanese grid				
Sulfate ion (-4)	surface water	2.93e-03	97.46%	
Suspended solids	surface water	7.63e-05	2.54%	
Total		**3.01e-03**	100.00%	**0.24%**
U.S. grid				
Sulfate ion (-4)	treatment	1.32e-04	97.46%	
Suspended solids	treatment	3.45e-06	2.54%	
Total		**1.36e-04**	100.00%	**0.01%**
Fuels				
Acids (H+)	surface water	1.76e-08	<0.01%	
Adsorbable organic halides	surface water	1.82e-11	<0.01%	
Aluminum (+3)	surface water	6.88e-06	<0.01%	
Ammonia ions	surface water	1.33e-03	0.18%	
Aromatic hydrocarbons	surface water	4.25e-09	<0.01%	
Barium cmpds	surface water	1.36e-08	<0.01%	
BOD	surface water	9.12e-03	1.23%	
Cadmium cmpds	surface water	1.42e-11	<0.01%	
Chloride ions	surface water	2.65e-01	35.77%	
Chromium (III)	surface water	3.49e-09	<0.01%	
Chromium (VI)	surface water	3.49e-09	<0.01%	
COD	surface water	7.71e-02	10.42%	
Copper (+1 & +2)	surface water	2.84e-10	<0.01%	
Cyanide (-1)	surface water	1.99e-11	<0.01%	
Dissolved organics	surface water	4.67e-08	<0.01%	
Dissolved solids	surface water	2.01e-05	<0.01%	
Fluorides (F-)	surface water	1.76e-06	<0.01%	
Halogenated matter (organic)	surface water	5.67e-12	<0.01%	
Hydrocarbons, remaining unspeciated	surface water	1.70e-05	<0.01%	
Iron (+2 & +3)	surface water	1.73e-08	<0.01%	
Lead cmpds	surface water	5.67e-11	<0.01%	
Mercury compounds	surface water	6.52e-14	<0.01%	
Metals, remaining unspeciated	surface water	4.72e-04	0.06%	
Nickel cmpds	surface water	2.84e-11	<0.01%	
Nitrate	surface water	2.97e-06	<0.01%	
Other nitrogen	surface water	7.66e-10	<0.01%	
Phenol	surface water	1.75e-04	0.02%	
Phosphates	surface water	2.83e-08	<0.01%	

Table 2-60. LCD manufacturing stage water outputs

Material	Disposition	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process Group				
Polycyclic aromatic hydrocarbons	surface water	6.81e-11	<0.01%	
Salts (unspecified)	surface water	7.84e-05	0.01%	
Sodium (+1)	surface water	3.41e-01	46.05%	
Sulfate ion (-4)	surface water	4.36e-06	<0.01%	
Sulfide	surface water	9.86e-09	<0.01%	
Suspended solids	surface water	4.14e-02	5.59%	
TOCs	surface water	4.25e-08	<0.01%	
Toluene	surface water	6.24e-10	<0.01%	
Waste oil	surface water	4.87e-03	0.66%	
Zinc (+2)	surface water	1.40e-09	<0.01%	
Total		**7.40e-01**	100.27%	**60.02%**
Grand Total		**1.23e+00**		**100.00%**

Table 2-61. LCD manufacturing stage hazardous waste outputs

Material	Disposition	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process Group				
Monitor/module				
Mercury	recycling/reuse	2.00e-06	<0.01%	
Waste metals, unspecified	recycling/reuse	1.17e-03	0.03%	
Waste acids, unspecified	recycling/reuse	3.24e-02	0.76%	
Waste acid (mainly HF)	recycling/reuse	5.69e-01	13.30%	
Waste acid (mainly HF)	treatment	1.36e-01	3.17%	
Unspecified sludge	land (other than landfill)	3.09e-02	0.72%	
Thinner, unspecified	treatment	5.40e-01	12.62%	
Tetramethyl ammonium hydroxide	recycling/reuse	1.42e-01	3.33%	
Sodium sulfate	recycling/reuse	2.44e-01	5.72%	
Rinse, unspecified	recycling/reuse	4.67e-02	1.09%	
Remover, unspecified	recycling/reuse	8.84e-02	2.07%	
Remover, unspecified	treatment	3.03e-01	7.08%	
Phosphoric acid	landfill	1.44e-02	0.34%	
Nitric acid	landfill	3.43e-04	0.01%	
Isopropyl alcohol	recycling/reuse	1.69e-01	3.95%	
Isopropyl alcohol	treatment	1.91e+00	44.75%	
Ferric chloride	recycling/reuse	1.37e-02	0.32%	
Acetone	treatment	2.77e-02	0.65%	
Acetic acid	landfill	4.46e-03	0.10%	
Total		**4.28e+00**	100.00%	**92.11%**
Panel components				
Spent solvents (F003 waste)	treatment	2.74e-04	0.24%	
Flammable liquids (F003 waste)	treatment	9.13e-04	0.80%	
Acid waste (D002 waste)	treatment	1.19e-03	1.04%	
Spent solvent (with halogenated materials)	treatment	1.55e-02	13.63%	
Spent solvent (non-halogenated)	treatment	4.66e-02	40.89%	
HCFC-225cb	recycling/reuse	3.11e-05	0.03%	
HCFC-225ca	recycling/reuse	3.11e-05	0.03%	
Waste solvent (photoresist)	recycling/reuse	2.05e-02	18.00%	
Waste solvent (photoresist)	treatment	2.17e-02	19.05%	
Waste acid (chrome mixed acid)	recycling/reuse	7.18e-03	6.29%	
Total		**1.14e-01**	100.00%	**2.46%**
LCD glass				
Waste Batch (Ba, Pb) (D008 waste)	landfill	6.55e-05	8.18%	
Waste acid (mostly 3% HCl solution)	recycling/reuse	1.82e-04	22.74%	
Hydrofluoric acid	landfill	8.24e-05	10.29%	
Chrome liquid waste (D007 waste)	recycling/reuse	4.54e-04	56.70%	
Chrome debris (D007 waste)	treatment	6.83e-06	0.85%	
Barium debris (D008 waste)	landfill	9.91e-06	1.24%	
Total		**8.01e-04**	100.00%	**0.02%**

Table 2-61. LCD manufacturing stage hazardous waste outputs

Material	Disposition	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process Group				
Backlight				
Hazardous waste, unspecified	recycling/reuse	1.42e-02	67.68%	
Hazardous waste, unspecified	treatment	6.80e-03	32.31%	
Waste glass, with mercury	landfill	1.05e-10	<0.01%	
Waste CCFL, with mercury	treatment	8.17e-10	<0.01%	
Waste CCFL, with lead	treatment	8.17e-08	<0.01%	
Silver	landfill	2.72e-09	<0.01%	
Chromium	landfill	1.52e-06	0.01%	
Total		**2.11e-02**	100.00%	**0.45%**
PWB				
PWB-Waste cupric etchant	recycling/reuse	9.93e-02	49.42%	
PWB-Solder dross	recycling/reuse	2.96e-02	14.72%	
PWB-Route dust	recycling/reuse	5.31e-03	2.64%	
PWB-Lead contaminated waste oil	treatment	5.14e-03	2.56%	
PWB-Decontaminating debris	treatment	6.85e-03	3.41%	
Hazardous waste, unspecified	treatment	5.48e-02	27.26%	
Total		**2.01e-01**	100.00%	**4.33%**
Fuels				
Hazardous waste, unspecified	landfill	**2.97e-02**		**0.64%**
Grand Total		**4.64e+00**		**100.00%**

Table 2-62. LCD manufacturing stage solid waste outputs

Material	Disposition	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process Group				
Monitor/module				
Isopropyl alcohol	treatment	1.03e-02	0.33%	
LCD panel waste	landfill	2.43e-02	0.77%	
Printed wiring board (PWB)	landfill	7.50e-03	0.24%	
Remover, unspecified	treatment	3.09e-02	0.98%	
Unspecified sludge	recycling/reuse	8.46e-01	26.79%	
Unspecified sludge	treatment	5.73e-02	1.82%	
Unspecified solid waste	recycling/reuse	2.02e-02	0.64%	
Waste acid (containing F and detergents)	landfill	2.70e-01	8.56%	
Waste acids, unspecified	treatment	1.05e-01	3.32%	
Waste alkali, unspecified	recycling/reuse	3.23e-01	10.24%	
Waste LCD glass	landfill	2.06e-01	6.52%	
Waste LCD glass	recycling/reuse	7.20e-01	22.80%	
Waste metals, unspecified	recycling/reuse	2.93e-03	0.09%	
Waste oil	treatment	1.61e-02	0.51%	
Waste plastic from LCD modules	recycling/reuse	7.40e-02	2.35%	
Waste plastic from LCD modules	treatment	4.03e-01	12.77%	
Waste plastics from LCD monitor	landfill	4.05e-02	1.28%	
Total		**3.16e+00**	100.00%	**25.07%**
Panel components				
Isopropyl alcohol	recycling/reuse	2.53e-02	11.75%	
Polyester resin	recycling/reuse	3.20e-02	14.84%	
Unspecified solid waste	treatment	1.10e-02	5.09%	
Used silica gel	landfill	6.22e-04	0.29%	
Waste alkali (color filter developer, unspecified)	recycling/reuse	8.91e-02	41.37%	
Waste LCD glass	landfill	5.74e-02	26.66%	
Total		**2.15e-01**	100.00%	**1.71%**
LCD glass				
abrasive sludge	recycling/reuse	1.95e-03	32.61%	
acid absorbent	landfill	3.77e-06	0.06%	
blasting media	landfill	1.70e-05	0.28%	
Cinders from LCD glass mfg	landfill	3.83e-04	6.40%	
Cobalt nitrate	treatment	2.83e-06	0.05%	
Diesel fuel	treatment	1.88e-06	0.03%	
Dust	treatment	1.59e-04	2.65%	
LCD glass EP dust	landfill	4.77e-05	0.80%	
LCD glass EP dust	recycling/reuse	2.32e-04	3.88%	
LCD glass, unspecified	landfill	1.13e-03	18.83%	
Nickel nitrate	treatment	2.83e-06	0.05%	
Oily rags & filter media	landfill	1.51e-05	0.25%	
Oily rags & filter media	recycling/reuse	1.88e-06	0.03%	

Table 2-62. LCD manufacturing stage solid waste outputs

Material	Disposition	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process Group				
parts cleaner solvent	recycling/reuse	3.77e-06	0.06%	
Plating process sludge	landfill	1.52e-05	0.25%	
Potassium Carbonate	landfill	1.53e-04	2.55%	
sludge (calcium fluoride, CaF2)	recycling/reuse	8.13e-04	13.59%	
Sludge from LCD glass mfg	landfill	4.06e-05	0.68%	
Sodium Carbonate	landfill	1.53e-04	2.55%	
Unspecified sludge	landfill	3.56e-04	5.95%	
Waste alkali, unspecified	treatment	1.95e-06	0.03%	
Waste LCD glass	landfill	8.70e-05	1.45%	
Waste oil	treatment	3.03e-04	5.07%	
Waste refractory	landfill	1.13e-04	1.89%	
Total		**5.98e-03**	100.00%	**0.05%**
Backlight				
Broken CCFL	landfill	2.69e-07	<0.01%	
Cardboard	treatment	1.82e-05	0.34%	
Polyethylene, foamed	treatment	9.99e-04	18.50%	
Polyethylene/polypropylene waste	treatment	2.72e-03	50.45%	
Unspecified nonhazardous waste	recycling/reuse	1.26e-04	2.32%	
Waste backlight casing (PC)	landfill	1.46e-05	0.27%	
Waste backlight light guide (PMMA)	landfill	1.52e-03	28.12%	
Total		**5.40e-03**	100.00%	**0.04%**
PWB				
PWB-Drill dust	landfill	6.59e-03	0.36%	
Unspecified solid waste	recycling/reuse	1.91e-01	10.53%	
Unspecified solid waste	treatment	1.62e+00	89.11%	
Total		**1.81e+00**	100.00%	**14.40%**
Japanese grid				
Coal waste	landfill	2.18e+00	61.12%	
Dust/sludge	landfill	8.42e-01	23.59%	
Fly/bottom ash	landfill	5.45e-01	15.28%	
Total		**3.57e+00**	100.00%	**28.34%**
U.S. grid				
Coal waste	landfill	9.85e-02	61.10%	
Dust/sludge	landfill	3.81e-02	23.63%	
Fly/bottom ash	landfill	2.46e-02	15.27%	
Total		**1.61e-01**	100.00%	**1.28%**
Fuels				
Aluminum scrap	recycling/reuse	8.77e-06	<0.01%	
Aluminum scrap, Wabash 319	recycling/reuse	2.37e-08	<0.01%	
Bauxite residues	landfill	5.87e-04	0.02%	
FGD sludge	landfill	1.09e-02	0.30%	
Mineral waste	landfill	1.26e-04	<0.01%	

Table 2-62. LCD manufacturing stage solid waste outputs

Material	Disposition	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process Group				
Mixed industrial (waste)	landfill	4.83e-02	1.32%	
Non toxic chemical waste (unspecified)	landfill	2.95e-05	<0.01%	
Slag and ash	landfill	3.40e+00	92.69%	
Slag and ash	recycling/reuse	3.49e-02	0.95%	
Unspecified solid waste (incinerated)	treatment	6.44e-04	0.02%	
Unspecified waste	landfill	1.72e-01	4.70%	
Total		**3.66e+00**	100.00%	**29.10%**
Grand Total		**1.26e+01**		**100.00%**

Table 2-63. LCD manufacturing stage radioactive waste outputs

Material	Disposition	Quantity (kg/ functional unit)	% of process group total	% of grand total
Process Group				
Japanese grid				
Low-level radioactive waste	landfill	3.71e-04	76.93%	
Uranium, depleted	landfill	1.11e-04	23.07%	
Total		**4.82e-04**	100.00%	**99.09%**
U.S. grid				
Low-level radioactive waste	landfill	3.40e-06	76.93%	
Uranium, depleted	landfill	1.02e-06	23.07%	
Total		**4.42e-06**	100.00%	**0.91%**
Grand Total		**4.87e-04**		**100.00%**

Table 2-64. LCD manufacturing stage radioactivity outputs

Material	Disposition	Quantity (Bq/ functional unit)	% of process group total	% of grand total
Process Group				
Japanese grid				
Antimony-124 (isotope)	treatment	1.67e+00	<0.01%	
Antimony-125 (isotope)	treatment	6.63e+00	<0.01%	
Argon-41 (isotope)	air	3.37e+03	0.03%	
Barium-140 (isotope)	treatment	1.23e-01	<0.01%	
Bromine-89 (isotope)	air	3.90e-04	<0.01%	
Bromine-90 (isotope)	air	1.59e-04	<0.01%	
Cesium-134 (isotope)	air	1.07e-02	<0.01%	
Cesium-134 (isotope)	treatment	4.45e+00	<0.01%	
Cesium-137 (isotope)	air	8.08e-02	<0.01%	
Cesium-137 (isotope)	treatment	6.69e+00	<0.01%	
Chromium-51 (isotope)	air	2.11e-01	<0.01%	
Chromium-51 (isotope)	treatment	8.02e+00	<0.01%	
Cobalt-57 (isotope)	air	5.68e-04	<0.01%	
Cobalt-57 (isotope)	treatment	1.94e-01	<0.01%	
Cobalt-58 (isotope)	air	7.26e-03	<0.01%	
Cobalt-58 (isotope)	treatment	7.90e+01	<0.01%	
Cobalt-60 (isotope)	air	5.46e-02	<0.01%	
Cobalt-80 (isotope)	treatment	2.07e+01	<0.01%	
Iodine-131 (isotope)	air	2.55e-01	<0.01%	
Iodine-131 (isotope)	treatment	3.70e+00	<0.01%	
Iodine-132 (isotope)	air	5.18e-02	<0.01%	
Iodine-132 (isotope)	treatment	1.40e+00	<0.01%	
Iodine-133 (isotope)	air	2.37e+02	<0.01%	
Iodine-133 (isotope)	treatment	1.59e+00	<0.01%	
Iodine-134 (isotope)	air	2.68e-01	<0.01%	
Iodine-135 (isotope)	air	1.35e-02	<0.01%	
Iodine-135 (isotope)	treatment	1.14e+00	<0.01%	
Iron-55 (isotope)	treatment	1.89e+01	<0.01%	
Iron-59 (isotope)	treatment	9.70e-01	<0.01%	
Krypton-85 (isotope)	air	5.59e+03	0.06%	
Krypton-85M (isotope)	air	2.71e+02	<0.01%	
Krypton-85M (isotope)	treatment	5.00e+00	<0.01%	
Krypton-87 (isotope)	air	1.01e+02	<0.01%	
Krypton-88 (isotope)	air	4.73e+02	<0.01%	
Lanthanum-140 (isotope)	treatment	1.32e-01	<0.01%	
Manganese-54 (isotope)	air	3.00e-03	<0.01%	
Manganese-54 (isotope)	treatment	5.29e+00	<0.01%	
Molybdenum-99 (isotope)	treatment	9.98e+06	98.42%	
Niobium-95 (isotope)	air	1.19e-04	<0.01%	
Niobium-95 (isotope)	treatment	1.36e+00	<0.01%	
Rubidium-88 (isotope)	air	1.11e+00	<0.01%	

Table 2-64. LCD manufacturing stage radioactivity outputs

Material	Disposition	Quantity (Bq/ functional unit)	% of process group total	% of grand total
Process Group				
Ruthenium-103 (isotope)	treatment	1.67e-01	<0.01%	
Silver-110M (isotope)	air	3.56e-06	<0.01%	
Silver-110M (isotope)	treatment	1.94e+00	<0.01%	
Sodium-24 (isotope)	treatment	2.96e-01	<0.01%	
Strontium-89 (isotope)	treatment	3.20e-01	<0.01%	
Strontium-90 (isotope)	treatment	7.52e-02	<0.01%	
Strontium-95 (isotope)	treatment	8.29e-01	<0.01%	
Sulfur-136 (isotope)	treatment	1.78e-01	<0.01%	
Technetium-99M (isotope)	air	1.60e-05	<0.01%	
Technetium-99M (isotope)	treatment	1.16e-01	<0.01%	
Tin-113 (isotope)	treatment	1.84e-01	<0.01%	
Tritium-3 (isotope)	air	7.90e+03	0.08%	
Tritium-3 (isotope)	treatment	5.91e+04	0.58%	
Xenon-131M (isotope)	air	4.56e+02	<0.01%	
Xenon-131M (isotope)	treatment	6.08e+01	<0.01%	
Xenon-133 (isotope)	air	4.37e+03	0.04%	
Xenon-133 (isotope)	treatment	9.34e+03	0.09%	
Xenon-133M (isotope)	air	6.58e+04	0.65%	
Xenon-133M (isotope)	treatment	7.65e+01	<0.01%	
Xenon-135 (isotope)	air	2.48e+03	0.02%	
Xenon-135 (isotope)	treatment	6.97e+01	<0.01%	
Xenon-135M (isotope)	air	4.74e+01	<0.01%	
Xenon-138 (isotope)	air	1.57e+02	<0.01%	
Zinc-85 (isotope)	treatment	8.92e-02	<0.01%	
Zirconium-95 (isotope)	air	3.08e-04	<0.01%	
Total		**1.01e+07**	100.00%	**99.09%**
U.S. grid				
Antimony-124 (isotope)	treatment	1.53e-02	<0.01%	
Antimony-125 (isotope)	treatment	6.09e-02	<0.01%	
Argon-41 (isotope)	air	3.09e+01	0.03%	
Barium-140 (isotope)	treatment	1.13e-03	<0.01%	
Bromine-89 (isotope)	air	3.58e-06	<0.01%	
Bromine-90 (isotope)	air	1.45e-06	<0.01%	
Cesium-134 (isotope)	air	9.82e-05	<0.01%	
Cesium-134 (isotope)	treatment	4.09e-02	<0.01%	
Cesium-136 (isotope)	treatment	1.75e-03	<0.01%	
Cesium-137 (isotope)	air	7.41e-04	<0.01%	
Cesium-137 (isotope)	treatment	6.13e-02	<0.01%	
Chromium-51 (isotope)	air	1.94e-03	<0.01%	
Chromium-51 (isotope)	treatment	7.36e-02	<0.01%	
Cobalt-57 (isotope)	air	5.21e-06	<0.01%	
Cobalt-57 (isotope)	treatment	1.78e-03	<0.01%	

Table 2-64. LCD manufacturing stage radioactivity outputs

Material	Disposition	Quantity (Bq/ functional unit)	% of process group total	% of grand total
Process Group				
Cobalt-58 (isotope)	air	6.65e+00	<0.01%	
Cobalt-58 (isotope)	treatment	7.25e-01	<0.01%	
Cobalt-60 (isotope)	air	5.01e-04	<0.01%	
Cobalt-80 (isotope)	treatment	1.90e-01	<0.01%	
Iodine-131 (isotope)	air	2.34e-03	<0.01%	
Iodine-131 (isotope)	treatment	3.39e-02	<0.01%	
Iodine-132 (isotope)	air	4.75e-04	<0.01%	
Iodine-132 (isotope)	treatment	1.28e-02	<0.01%	
Iodine-133 (isotope)	air	2.17e+00	<0.01%	
Iodine-133 (isotope)	treatment	1.45e-02	<0.01%	
Iodine-134 (isotope)	air	2.46e-03	<0.01%	
Iodine-135 (isotope)	air	1.24e-04	<0.01%	
Iodine-135 (isotope)	treatment	1.04e-02	<0.01%	
Iron-55 (isotope)	treatment	1.73e-01	<0.01%	
Iron-59 (isotope)	treatment	8.90e-03	<0.01%	
Krypton-85 (isotope)	air	5.13e+01	0.06%	
Krypton-85M (isotope)	air	2.48e+00	<0.01%	
Krypton-85M (isotope)	treatment	4.58e-02	<0.01%	
Krypton-87 (isotope)	air	9.25e-01	<0.01%	
Krypton-88 (isotope)	air	4.34e+00	<0.01%	
Lanthanum-140 (isotope)	treatment	1.21e-03	<0.01%	
Manganese-54 (isotope)	air	2.75e-05	<0.01%	
Manganese-54 (isotope)	treatment	4.85e-02	<0.01%	
Molybdenum-99 (isotope)	treatment	9.15e+04	98.41%	
Niobium-95 (isotope)	air	1.09e-06	<0.01%	
Niobium-95 (isotope)	treatment	1.25e-02	<0.01%	
Rubidium-88 (isotope)	air	1.02e-02	<0.01%	
Ruthenium-103 (isotope)	treatment	1.53e-03	<0.01%	
Silver-110M (isotope)	air	3.26e-08	<0.01%	
Silver-110M (isotope)	treatment	1.78e-02	<0.01%	
Sodium-24 (isotope)	treatment	2.72e-03	<0.01%	
Strontium-89 (isotope)	treatment	2.93e-03	<0.01%	
Strontium-90 (isotope)	treatment	6.90e-04	<0.01%	
Strontium-95 (isotope)	treatment	7.60e-03	<0.01%	
Sulfur-136 (isotope)	treatment	1.64e-03	<0.01%	
Technetium-99M (isotope)	air	1.47e-07	<0.01%	
Technetium-99M (isotope)	treatment	1.06e-03	<0.01%	
Tin-113 (isotope)	treatment	1.68e-03	<0.01%	
Tritium-3 (isotope)	air	7.25e+01	0.08%	
Tritium-3 (isotope)	treatment	5.42e+02	0.58%	
Xenon-131M (isotope)	air	4.18e+00	<0.01%	
Xenon-131M (isotope)	treatment	5.58e-01	<0.01%	

Table 2-64. LCD manufacturing stage radioactivity outputs

Material	Disposition	Quantity (Bq/ functional unit)	% of process group total	% of grand total
Process Group				
Xenon-133 (isotope)	air	6.04e+02	0.65%	
Xenon-133 (isotope)	treatment	8.57e+01	0.09%	
Xenon-133M (isotope)	air	4.01e+01	0.04%	
Xenon-133M (isotope)	treatment	7.02e-01	<0.01%	
Xenon-135 (isotope)	air	2.28e+01	0.02%	
Xenon-135 (isotope)	treatment	6.39e-01	<0.01%	
Xenon-135M (isotope)	air	4.35e-01	<0.01%	
Xenon-138 (isotope)	air	1.44e+00	<0.01%	
Zinc-85 (isotope)	treatment	8.18e-04	<0.01%	
Zirconium-95 (isotope)	air	2.82e-06	<0.01%	
Total		**9.30e+04**	100.00%	**0.91%**
Fuels				
Radioactive substance (unspecified)	air	4.44e+01	99.08%	
Radioactive substance (unspecified)	surface water	4.11e-01	0.92%	
Total		**4.48e+01**	100.00%	**0.00%**
Grand Total		**1.02e+07**		**100.00%**

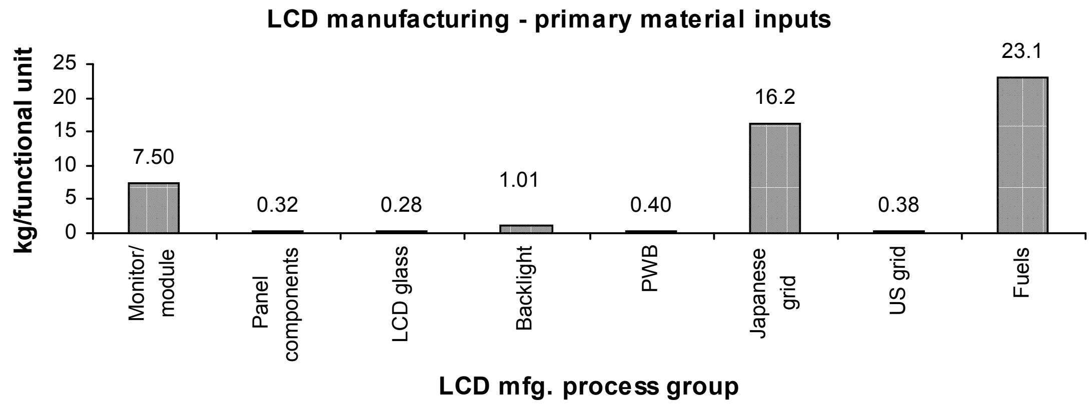

Figure 2-51. LCD manufacturing primary material inputs

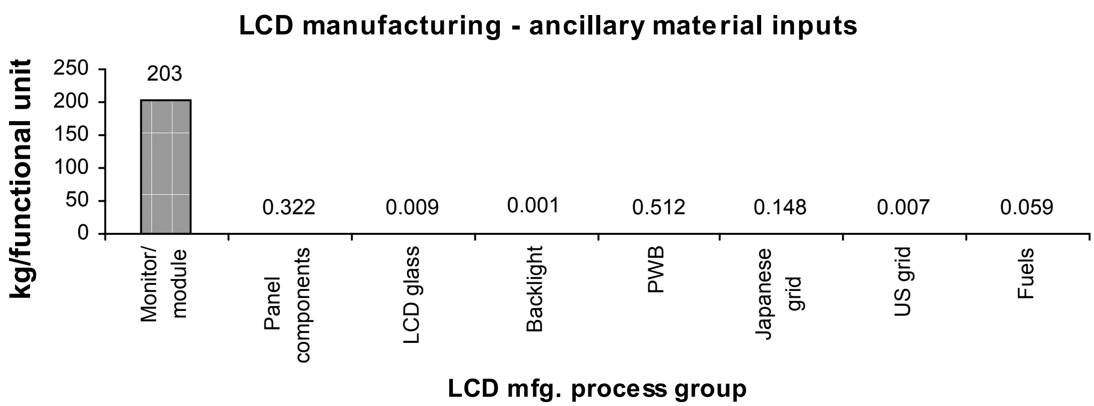

Figure 2-52. LCD manufacturing ancillary material inputs

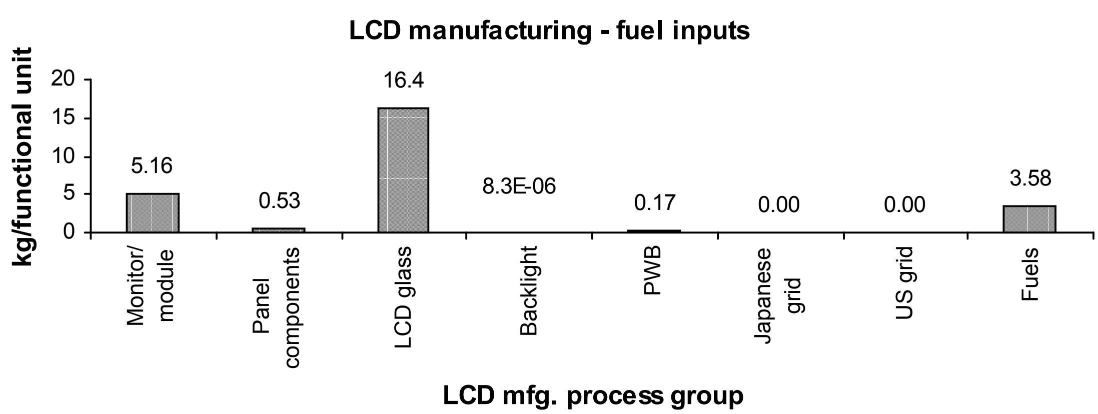

Figure 2-53. LCD manufacturing fuel inputs

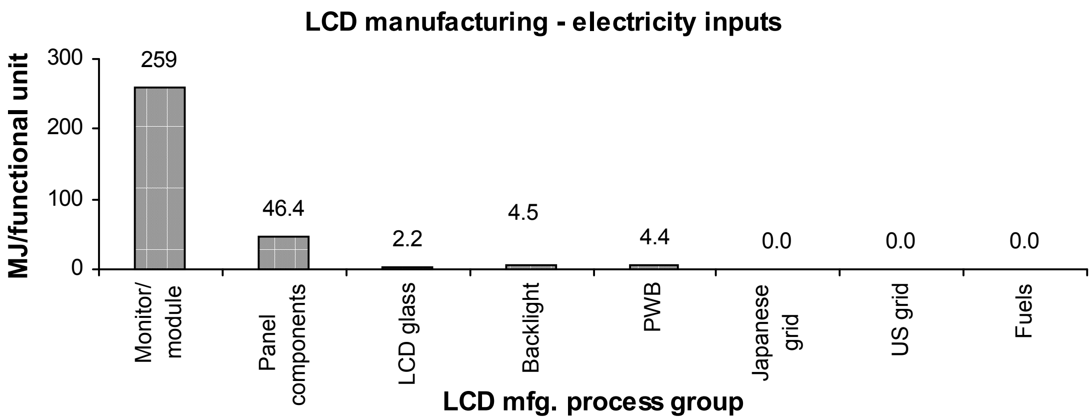

Figure 2-54. LCD manufacturing electricity inputs

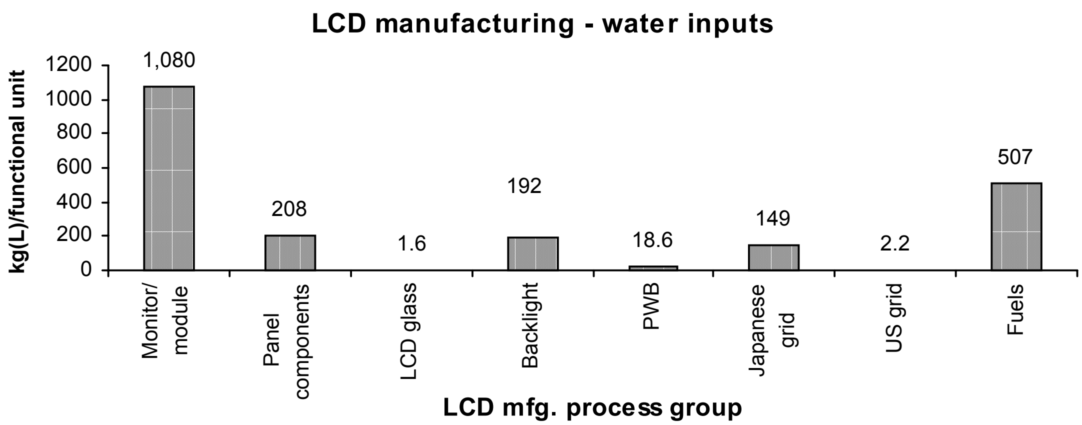

Figure 2-55. LCD manufacturing water inputs

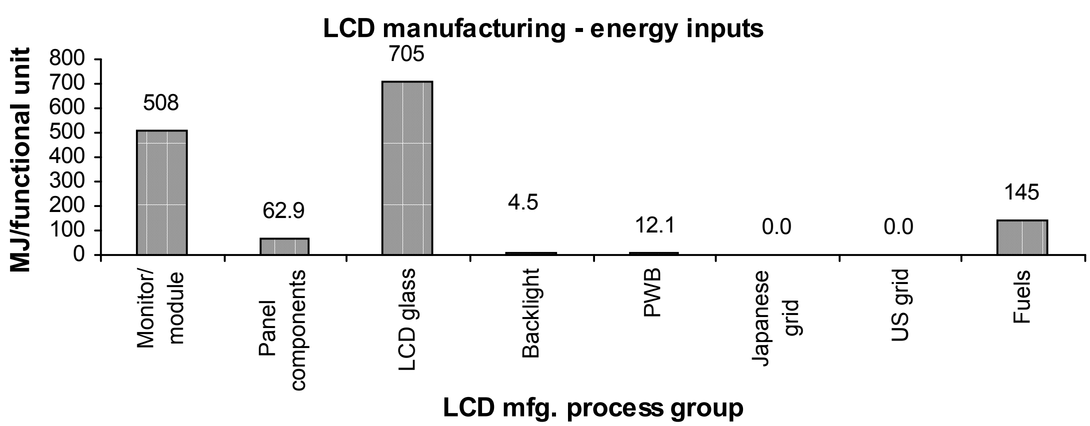

Figure 2-56. LCD manufacturing energy inputs

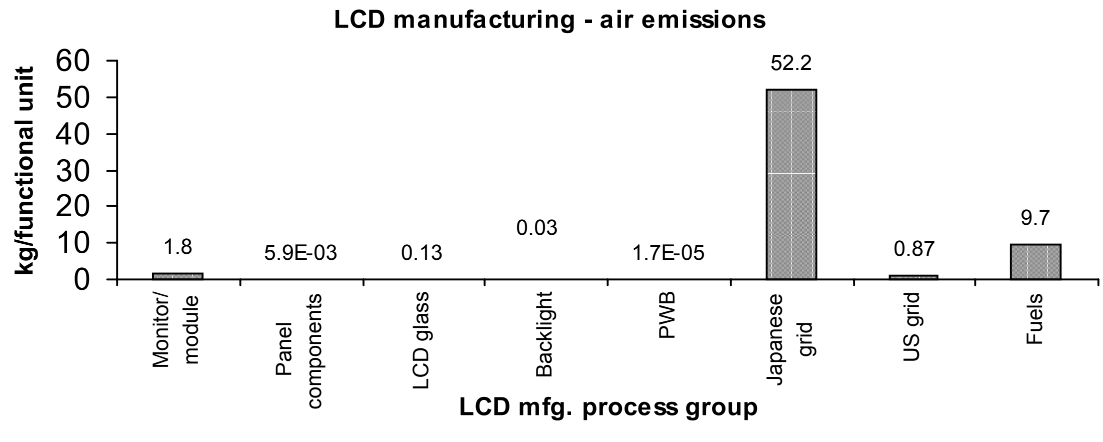

Figure 2-57. LCD manufacturing air pollutant outputs

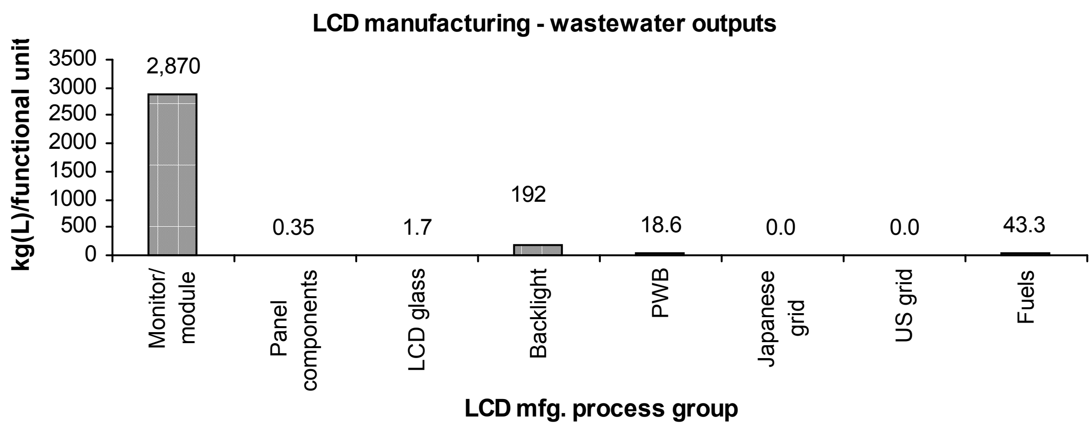

Figure 2-58. LCD manufacturing wastewater outputs

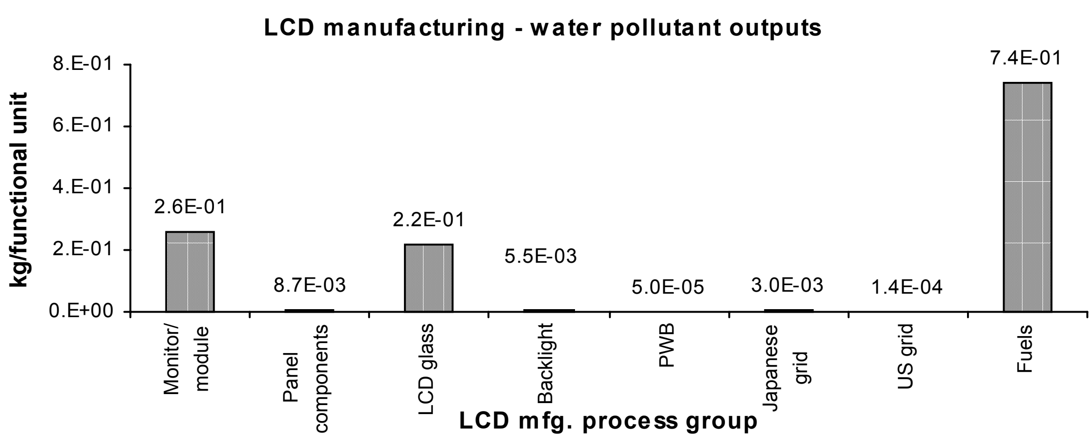

Figure 2-59. LCD manufacturing water pollutant outputs

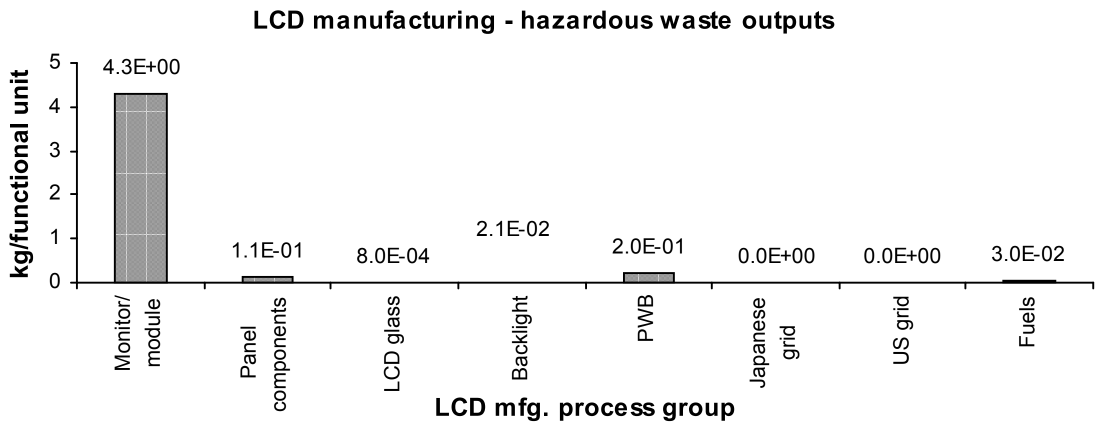

Figure 2-60. LCD manufacturing hazardous waste outputs

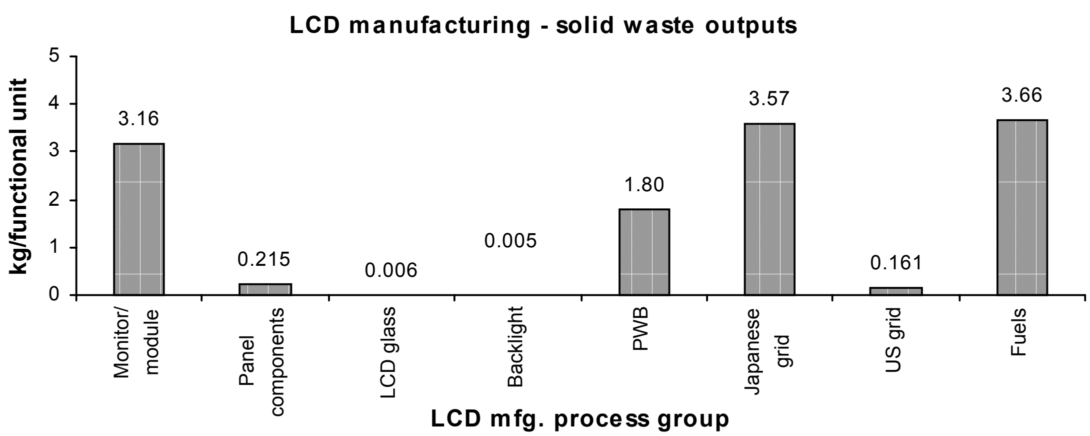

Figure 2-61. LCD manufacturing solid waste outputs

Of the total 49 kg of primary materials per functional unit in the manufacturing stage, the fuels production contributes the greatest (23.1 kg/functional unit), followed by the Japanese electric grid (16.2 kg/functional unit) (Figure 2-51 and Table 2-56). Nearly all (203 out of 204 kg/functional unit) of the ancillary materials used during manufacturing are from the monitor/module process group (Figure 2-52 and Table 2-57). Liquified natural gas (LNG) constitutes about 96% (194 kg/functional unit) of the total ancillary materials in the monitor/module process group. As stated earlier, this is not used to calculate energy impacts.

Of the utility inputs, electricity and water inputs were greatest in the monitor/module manufacturing processes; fuels were greatest in the LCD glass manufacturing process group (Figures 2-53, 2-54, and 2-55). Sixty-three percent of the fuel inputs are from the LCD glass manufacturing process group. Within that group, the use of LPG clearly dominates at about 16.2 kg/functional unit (over 99% of the LCD glass fuel inputs) (Table 2-58).[6] The monitor/module manufacturing fuel inputs are about 20% of the total manufacturing fuel inputs (5.2 kg/functional unit). About 259 MJ/functional unit of electricity in the LCD manufacturing stage are from the monitor/module processes[7], or 82% of all manufacturing electricity (Figure 2-54). The total energy, which converts fuel mass into energy and adds that to the electrical energy, is greatest in the LCD glass manufacturing processes and contributes 705 MJ/functional unit to the 1,440 MJ/functional unit in the manufacturing stage (Figure 2-56). Water inputs are most significant in the monitor/module manufacturing process, contributing 1,080 kg (or liter)/functional unit (Figure 2-55), which is 50% of all the manufacturing water inputs. The fuels production and panel components process groups contribute about 24% and 10% to the water manufacturing inputs, respectively.

For outputs from the manufacturing stage, the mass of air emissions are dominated by the generation of electricity (Figure 2-57). Individual material (pollutant) contributions for each process group are presented in Table 2-59. Wastewater outputs (i.e., the volume or mass of wastewater released) are greatest for the monitor/module manufacturing processes (92%) (Figure 2-58), but only 21% of the chemical pollutants in the wastewater streams come from those processes (Figure 2-59). Table 2-60 shows the individual contributions from each material.

Hazardous wastes from the LCD manufacturing stage dominated over other life-cycle stages, and within the manufacturing stage, the monitor/module processes had the greatest hazardous waste outputs by mass (4.3 kg/functional unit) (Figure 2-60). The greatest contributors by mass are isopropyl alcohol (a total of 2.1 kg/functional unit, or 49% of all wastes from the monitor/module manufacturing processes) (Table 2-61). These wastes, however, are recycled and although they are a large portion of the inventory, they will not affect the impact assessment (to be presented in Chapter 3) as they are not directly released to the environment.

Solid wastes generated during the manufacturing stage were only about 21% of the overall solid wastes generated throughout the LCD life-cycle, as was shown earlier in

[6] Note: An industry participant questioned the large fuel contribution reported here; however, further discussions with industry supported that no valid reason could justify removing these data. Glass energy inputs are evaluated in a sensitivity analysis (see Section 2.7.3 and 3.4).

[7] This amount of electricity is consistent with the industry participant that expressed doubt in the large fuel energy contribution and subsequent overall energy use amount in module manufacturing.

Figure 2-48. Within the manufacturing stage, the fuels production, Japanese grid and monitor/module manufacturing process groups are all major contributors to the solid waste outputs (Figure 2-61). The individual material contributions are provided in Table 2-62.

Radioactive waste and radioactivity are directly related to the electricity generation process and therefore, only the Japanese and U.S. electric grid processes generate these outputs in the manufacturing stage. Tables 2-63 and 2-64 show that more radioactive wastes and radioactivity are from the Japanese electric grid. This is a result of more manufacturing processes being in Japan, as modeled in this project, as well as the greater fraction of nuclear power in the Japanese electric grid.

2.7.2 Relative Data Quality

Sections 2.2 through 2.6 (and associated appendices) discuss the data quality and data limitations for each life-cycle stage. Several factors contribute to the overall quality for an entire life-cycle stage. For example, the manufacturing stage includes several different processes that were collected from several different companies. The quality of one data set from one company may be very different from that of another company. Relative data quality estimates have been made for each life-cycle stage, including electricity generation, which is included in more than one life-cycle stage (Table 2-65). In addition, transportation data quality is listed in Table 2-65, although it has been excluded from the analysis due to the very low data quality.

Table 2-65. Relative data quality

Life-cycle stage	Relative data quality
Upstream	Moderate
Manufacturing	Moderate to high
Use	Moderate to high
EOL	Low to moderate
Electricity generation	High
Transportation	Very low

2.7.3 Sensitivity Analyses

The inventory results presented above in Section 2.7.1 are the “baseline” results in this study. The baseline scenario includes the parameters/assumptions presented in the methodologies for the effective life scenario. However, due to assumptions and uncertainties in this LCA, as in any LCA, sensitivity analyses on the baseline results have been conducted. Four areas have been identified where sensitivity analyses were most warranted:

- use stage lifespan assumptions;
- glass manufacturing energy inputs;
- LCD monitor/module manufacturing energy inputs, and
- LCD EOL disposition assumptions.

Selected sensitivity analyses were chosen based on the data with either the greatest uncertainties or with a large uncertainty and a major contributor to the inventory results. The matrix in Table

2-66 shows the different sensitivity analyses or scenarios that are considered in the impact assessment results. Discussions of the sensitivity analyses for manufactured life (use stage), glass manufacturing energy inputs, LCD monitor manufacturing energy inputs, and LCD EOL inventories follow in this section. Complete inventories of each sensitivity analysis scenario are not presented; however, the effects determined in the LCIA results of the sensitivity analyses are shown in Chapter 3 (see Section 3.4).

Table 2-66. List of sensitivity analysis scenarios

Monitor type	Sensitivity analysis scenario
Baseline analyses (for reference)	
CRT	Effective life scenario with average glass energy inputs (all glass manufacturing energy data used)
LCD	Effective life scenario with average glass energy inputs (all glass manufacturing energy data used) and outliers in the LCD module manufacturing energy data removed
Sensitivity analyses	
CRT	Manufactured life scenario same as baseline except lifespan is based on manufactured life instead of effective life, which results in some revised functional equivalency calculations (see Section 2.7.3.1 below)
LCD	Manufactured life scenario same as baseline except lifespan is based on manufactured life, which results in some revised functional equivalency calculations (see Section 2.7.3.1 below)
CRT	Modified glass energy scenario same as baseline except comparatively high glass manufacturing energy inputs are removed
LCD	Modified glass energy scenario same as baseline except comparatively high glass manufacturing energy inputs are removed
LCD	Modified LCD module energy scenario same as baseline except LCD monitor/ module manufacturing energy outliers are included in the average
LCD	Modifed LCD EOL scenario same as baseline except LCD EOL dispositions are modified

2.7.3.1 Manufactured life scenario

To address uncertainties in the use stage lifespan assumptions, we applied the manufacturing life scenario to the CRT and LCD life-cycle profiles. (See Section 2.4 for a discussion of the product use stage and the differences in the "effective life" versus "manufactured life" life span assumptions.) Recall that the LCD manufactured life (45,000 hours) is 3.6 times greater than the CRT manufactured life (12,500 hours). In an LCA, comparisons are made based on functional equivalency. Therefore, if one monitor will operate for a longer period of time than another, impacts should be based on an equivalent use. Thus, based on equivalent use periods, under the manufactured life scenario 3.6 CRTs would need to be manufactured for every LCD. This was incorporated into the profile analysis for the comparative manufactured life LCA. Similarly, on average, 1.4 LCD backlights (which can be cost-effectively replaced) will be needed during the manufactured lifetime of an LCD monitor. This was also incorporated into the profile. Thus, the following modifications were made:

- change the CRT electricity input in the use stage from 635 kWh (2,286 MJ) to 788 kWh (2,837 MJ); [8]
- change the LCD electricity input in the use stage from 237 kWh (853 MJ) to 1,035 kWh (3,726 MJ);
- increase the manufacturing of CRTs by a factor of 3.6 to account for the functional equivalency of CRTs and LCDs. This was done by increasing the functional unit (22 kg CRT monitor) by a factor of 3.6, which equates to manufacturing 3.6 times more CRTs than in the baseline case; and
- increase the manufacturing of the LCD backlight lamp by a factor of 1.4 to account for the functional equivalency of LCDs and CRTs. This was done by increasing the backlight lamp mass (0.0023 kg), which is an input to the backlight unit assembly process, by a factor of 1.4.

Note that functional equivalency modification requires that the manufactured life scenario results be used only when comparing the CRT and LCD. These results cannot be accurately used to compare EL to ML for CRT or LCD. LCIA results of the sensitivity analysis are presented in Chapter 3.

2.7.3.2 Modified glass energy scenario

In the second case, the energy input values for CRT glass manufacturing (and consequently LCD glass manufacturing) were considered uncertain due to the large discrepancy in fuel and electricity values among the individual data sets. The baseline case uses the average of the data supplied and confirmed by the companies who supplied the data. However, because one set of data was significantly higher, that one set of data was removed from the profile for the sensitivity analysis. (A statistical evaluation of the glass manufacturing data for outliers could not be conducted because there were not enough data sets.)

In the baseline scenario, the averaged primary data from manufacturers of total energy to produce a kilogram of CRT or LCD glass was 1,560 MJ (433 kWh) of energy, with only 0.3% of that as electrical energy. The sensitivity analysis scenario assumes 16.3 MJ (4.5 kWh) per kilogram of glass produced, with approximately 30% as electrical energy. The majority of the fuel energy in the baseline scenario was from LPG. The energy consumption values can be compared to estimates for the entire glass industry, which includes the more prevalent general flat glass, as well as speciality glasses, such as CRT and LCD glass. In a report of the Glass Technology Roadmap Workshop (Energetics Inc. 1997), it was estimated that in practice, about 1.1 MJ of energy are required to melt a kilogram of glass; and electrical energy contributes approximately 13% of the total process energy requirements from glass production, as reported in 1994. Although this does not translate into energy requirements for CRT or LCD glass, it suggests the baseline data collected for this analysis may be inflated. Therefore, the sensitivity

[8] This represents the electricity use for a 12,500 hour life span. This figure is then multiplied by a factor of 3.6 in the functional equivalency calculations (see third bullet, below).

analysis uses revised energy input values for glass production, but it is also not known whether these values represent the true energy requirements for CRT and LCD glass production. The sensitivity analysis is considered a lower bound of energy requirements for monitor glass production.

2.7.3.3 Modified LCD module energy scenario

LCD monitor/module manufacturing energy was another area of relatively large uncertainty and variability in the inventory data. The CDP received seven sets of LCD monitor/module manufacturing data from five companies in Japan and two in Korea. Of these, the manufacturing energy data from one company in Korea was incomplete and could not be used. For the remaining six data sets, total energy inputs ranged from 330 MJ to 7,310 MJ, with a mean and standard deviation of 2,269 MJ and 2,906 MJ, respectively. Given the wide variability in the data and large standard deviation, CDP researchers evaluated the data for outliers by breaking the total energy data points into quartile ranges. Minor outliers are then those within a certain range of multipliers beyond the middle 50 percent of the distribution. That is, the interquartile range (IQR) (i.e., the range of values representing the middle 50 percent) multiplied by 1.5 is the lower bound of the minor outlier and the IQR times three is the upper bound of the minor outlier. Anything beyond IQR times three is a major outlier. Using this approach, one data set was found to be a minor outlier and another was found to be a major outlier. These outliers were excluded from the averages used in the baseline analysis, but included in the averages used in the LCD monitor/module manufacturing energy sensitivity analysis.

Table 2-67 summarizes the energy inputs for the LCD monitor/module manufacturing process group under the baseline and modified LCD module energy scenarios. Note that total energy inputs are approximately 4.5 times lower under the baseline scenario. However, because of the different types of energy (fuel and electricity) employed by different manufacturers, the mean electric energy is higher for the baseline than the modified energy scenario.

2.7.3.4 LCD End-of-life dispositions

Finally, because very few desktop LCDs have reached their end of life, and usually only if they have been damaged in some way, very little is known about the percentage of LCDs that are remanufactured, recycled, landfilled or incinerated. In the baseline scenario, it was assumed that a certain proportion of monitors go to each EOL disposition. As the functional unit in this study is one monitor, we used those proportions to represent the probability that one monitor would go to the respective disposition. To address uncertainties in the allocation of disposition percentages, a sensitivity analysis was conducted with a different set of final disposition numbers. Details and assumptions for the sensitivity analysis are provided in Appendix I. Table 2-68 presents the distribution of LCD EOL dispositions assumed under the baseline and modifed EOL dispositions scenarios. LCIA results for the sensitivity analysis are presented in Section 3.4.

Table 2-67. Energy inputs to the LCD monitor/module manufacturing process group under the baseline and modified energy scenarios

	Total energy (MJ per monitor)	Electric energy (MJ per monitor)	Fuel energy (MJ per monitor)	% electric energy	% fuel energy
Baseline (excludes two outlier data sets from the means used in the inventory)					
Range	333 to 934	199 to 359	48 to 695	25 to 88	12 to 75
Mean	508	259	249	60	40
Standard deviation	284	68	300	27	27
Modified Energy (includes two outlier data sets in the means used in the inventory)					
Range	333 to 7,317	125 to 359	48 to 7,146	2 to 88	12 to 98
Mean	2,274	222	2052	10	90
Standard deviation	2,906	79	2,956	36	36

Table 2-68. Distribution of LCD EOL dispositions in the baseline and modified EOL scenarios

Disposition	Baseline	Modified
Incineration	15%	15%
Recycling	15%	0%
Remanufacturing	15%	40%
Hazardous waste landfill	5%	5%
Solid waste landfill	50%	40%

REFERENCES

Bocko, P. 2000. Personal communication with P. Bocko, Corning Incorporated and M.L. Socolof, University of Tennessee Center for Clean Products and Clean Technologies. October 5.

CIA (Computer Industry Almanac, Inc.). 1997. Computer Industry Almanac. Arlington Heights, IL.

Douglas, D. 1999. Personal communication with D. Douglas and E. Korman, Dell, and J.G. Overly, University of Tennessee Center for Clean Products and Clean Technologies. March.

Ecobilan. 1999. DEAM, life-cycle inventory database developed by the *Ecobilan* Group, copyright 1999.

EIA (Energy Information Administration). 1997. *Country Energy Data Report for 1997.* Web site available at http://www.eia.doe.gov.

EIA. 1999a. *Electric Power Monthly, February 1999 (With Data for November 1998).* DOE/EIA-0226(99/02).

EIA. 1999b. "1997 Residential Energy Consumption Survey," Housing Characteristics report. Web site available at http://www.eia.doe.gov/emeu/consumption/reports.html (under 'Residential Households').

Energetics, Incorporated. 1997. *Report of the Glass Technology Roadmap Workshop*, April 24-25, 1997, Alexandria, Virginia. Sponsored by the U.S. Department of Energy, Corning, Incorporated, Fort Motor Company, Pilkington Libbey-Owens-Ford, Praxair, Inc., and Techneglas, Incorporated. Columbia, Maryland.

EPA (Environmental Protection Agency). 1996. *Compilation of Air Pollutant Emission Factors (AP-42), Fifth Edition, Volume I.* AP-42. January.

EPA. 1998. "Characterization of Municipal Solid Waste in the United States: 1997 Update." Report No. EPA530-R-98-007.

Fanara, A. 1999. Personal communication with A. Fanara, U.S. Environmental Protection Agency (EPA) Energy Star Program, and J.G. Overly, University of Tennessee Center for Clean Products and Clean Technologies. July.

FEPC (Federation of Electric Power Companies). 1996. "Electricity Review Japan: The FEPC." Web site available at http://www.fepc or jp/erj/data 03.html (1996 data).

Goldwasser, S.M. 1999. "Notes on the Troubleshooting and Repair of Computer and Video Monitors." Web site available at http://plop.phys.cwru.edu/repairfaq/REPAIR/F_monfaq.html.

ISO (International Standards Organization). 1996. *ISO 14040, Environmental Management - Life-cycle Assessment Principles and Framework.* TC 2071 SC 5N 77. International Standards Organization, Paris.

Lapp, J.C. 2000. Personal communication with J.C. Lapp, Corning Incorporated, and M.L. Socolof, University of Tennessee, Center for Clean Products and Clean Technologies. October 11 and October 23.

Matthews, H. S., *et al.* 1997. "Disposition and End-of-Life Options for Personal Computers." Green Design Initiative Technical Report #97-10. Carnegie Mellon University, Pittsburgh, PA. July.

McConnaughey, M. 1999. Personal communication with M. McConnaughey, ViewSonic, and J.G. Overly, University of Tennessee, Center for Clean Products and Clean Technologies. March.

MCC (Microelectronics and Computer Technology Corporation). 1998. *Computer Display Industry and Technology Profile*. EPA 744-R-98-005. December.

Nordman, B., M. A. Piette and K. Kinney. 1996. "Measured Energy Savings and Performance of Power-Managed Personal Computers and Monitors." Presented at the American Council for an Energy Efficient Economy Summer Study, Pacific Grove, CA. LBL-38057, UC-1600. August.

NSC (National Safety Council). 1999. *Electronic Product Recovery and Recycling Baseline Report: Recycling of Selected Electronic Products in the United States.* Washington, DC. May.

ORNL (Oak Ridge National Laboratory). 1994. *Report 3: Estimating Externalities of Coal Fuel Cycles.* Oak Ridge, TN. September.

ORNL. 1995. *Report 8: Estimating Externalities of Nuclear Fuel Cycles.* Oak Ridge, TN. April.

SETAC (Society of Environmental Toxicology and Chemistry). 1994. *Life-Cycle Assessment Data Quality: A Conceptual Framework*. SETAC and SETAC Foundation for Environmental Education, Inc., Washington, DC.

Sharp, J. 2000. Personal communication with J. Sharp, Teredyne Corp., J.G. Overly, University of Tennessee, Center for Clean Products and Clean Technologies, and M.L. Socolof, University of Tennessee, Center for Clean Products and Clean Technologies. August

Socolof, M.L, *et al.* 2000. "Preliminary Life-cycle Assessment Results for the Design for the Environment Computer Display Project." International Symposium on Electronics and the Environment, The Institute of Electrical and Electronics Engineers, Inc. (IEEE) Computer Society Conference Record, May 8-10, San Francisco, CA.

TORNRC (The Oak Ridge National Recycle Center). 2001. Personal communication with D. McFarland and A. Bradley, TORNRC, and R. Dhingra, University of Tennessee, Center for Clean Products and Clean Technologies. April.

Tsuda, D. 1999. Personal communication with D. Tsuda, Environmental Technologies and Strategies Department, Apple Computer, Inc., and M.L. Socolof, University of Tennessee, Center for Clean Products and Clean Technologies. July.

Vorhees, G. 2000. Personal communication with G. Vorhees, Envirocycle, and M.L. Socolof, University of Tennessee, Center for Clean Products and Clean Technologies. July.

Young, R. 1999. Personal communication with R. Young, Display Search, and M.L. Socolof, University of Tennessee, Center for Clean Products and Clean Technologies. August.

VP150. 1998. Viewsonic VP150 17" monitor specifications sheet.

Wood, S.P. 2000. Personal communication with S.P. Wood, Techneglas, and M.L. Socolof, University of Tennessee, Center for Clean Products and Clean Technologies. October 27.